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A WATER RESOURCE-WATER SUPPLY STUDY OF THE POTOMAC ESTUARY

Norbert A. Jaworski, et al

Environmental Protection Agency
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Environmental Protection Agency

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OF THE
POTOMAC ESTUARY

Technical Report 35

April 1971

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CHAPTER I

INTRODUCTION

At the third session of the Conference on the Matter of Pollution of the Interstate Waters of the Potomac River and Its Tributaries in the Washington Metropolitan Area held April 2, 3, 4 and again on May 8, 1969, the conferees agreed upon 15 recommendations to enhance the water quality of the Potomac and to assure adequate sewerage services for the area.

At the progress evaluation meeting of the conference held on November 6-7, 1969, a technical advisory committee was established to determine the studies required to evaluate water quality management needs of the upper estuary.

In November 1969, the Assistant Secretary of the Interior also requested a study of the water supply potential of the upper Potomac Estuary. Incorporating both the suggestions of the Potomac Enforcement Technical Advisory Committee and the request of the Assistant Secretary of the Interior, a detailed water quality-water resources study of the Potomac Estuary was undertaken by the Chesapeake Technical Support Laboratory.

The study included (1) an evaluation of pollution sources including nutrients, (2) the development and refinement of mathematical models to predict the effects of the various pollutants on water quality, (3) the projection of water supply needs and wastewater loadings, (4) an evaluation of the estuary as a potential water supply source, (5) the determination of the maximum pound loadings by zone for the various pollutants under various flow conditions, (6) an investigation of alternative waste treatment plans, and (7) an estimate of the cost of wastewater treatment required to maintain water quality standards.

During this study, close cooperation was maintained with the North Atlantic Division of the U. S. Army Corps of Engineers who were investigating the water supply potential of the upper Potomac Estuary as part of their Northeast Water Supply Study (NEWS) for the Washington metropolitan area.

CHAPTER II

SUMMARY AND CONCLUSIONS

A detailed study of the interrelationships among wastewater discharges, water supply withdrawals, freshwater inflow, and water quality in the Potomac Estuary was undertaken in November 1969. This study had two purposes: (1) to refine the allowable oxygen demanding and nutrient loadings previously established for Zones I, II, and III of the upper Potomac Estuary and (2) to determine the feasibility of using the estuary as a municipal water supply source. The latter study was conducted in cooperation with the U. S. Army Corps of Engineers. The study findings as related to wastewater management are presented below:

1. The Potomac River Basin has a drainage area of 14,670 square miles. The average discharge rate of the Potomac River at Great Falls is 10,780 cubic feet per second (cfs) with a minimum of 610 cfs and a maximum of over 484,000 cfs.

2. Of the present 3.3 million population in the Potomac River Basin, 2.8 million live within the study area which encompasses the entire Washington metropolitan region.

3. The present municipal water use within the study area is 370 mgd with 72 percent (265 mgd) supplied from the Potomac River above Washington. The industrial water use is 2,750 mgd with cooling water for electric power production accounting for 99 percent.

4. Recreational facilities on or near the Potomac Estuary include a national park, three state parks, seven fish and game areas and 226 county recreational sites. A recent study by the Bureau of Outdoor Recreation indicated that the recreational potential of the 637 miles of shoreline has barely been developed.

5. In 1969, approximately 17-million pounds of fish, crabs, clams, and oysters were taken from the Potomac tidal system with a dockside value of some $4.7 million. A study in 1961 indicated that about $0.6 million was spent during 6 months of sport fishing in the Potomac Estuary. There are approximately 95 marina facilities in the tidal Potomac which accommodate over 5,200 recreational watercraft.

6. Effluents from the 18 major wastewater treatment facilities and combined sewer overflows, with a total flow of 325 mgd, contribute 450,000, 24,000, and 60,000 lbs/day of ultimate oxygen demand (UOD*), phosphorus, and nitrogen respectively to the waters of the upper Potomac Estuary.

7. Under low-flow conditions, the ultimate oxygen demand, phosphorus, and nitrogen loadings from the upper basin and local runoff were estimated as 66,000, 1,000, and 2,300 lbs/day, respectively.

8. The major sources of nutrients and ultimate oxygen demand in the Potomac Estuary are the local wastewater discharges. Under low-flow conditions approximately 88, 90, and 96 percent of the ultimate oxygen demand, nitrogen, and phosphorus are from treated waste effluents.

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* UOD - Ultimate Oxygen Demand is defined as the sum of 1.45 times the 5-day biochemical oxygen demand and 4.57 times the unoxidized nitrogen.

At median freshwater inflows, approximately 62, 60, and 82 percent respectively are from these wastewater discharges.

9. Since the first sanitary surveys in 1913, the water quality of the upper Potomac Estuary has generally deteriorated. This is attributable to the increased pollution originating in the Washington area.

10. Fecal coliform densities have recently proved an exception to the general degradation as shown by the water quality indicators. Since the summer of 1969, the high fecal coliform densities previously found near the waste discharge points have been significantly reduced by continuous wastewater effluent chlorination. At present, the largest sources of bacterial pollution in the upper estuary are from sanitary and combined sewer overflows, where at times about 10 to 20 mgd of untreated sewage enters the estuary because of inadequate sewer and treatment capacities.

To achieve the adopted fecal coliform water quality standards, there must be both continuous disinfection of wastewater effluents and elimination or drastic reduction in overflows from sanitary and combined sewers.

11. The most pronounced effect of thermal discharges is in the Anacostia tidal river where a five-degree rise above ambient water temperature frequently occurs and readings as high as 33°C have been recorded during the summer months.

12. Since 1938, dissolved oxygen levels in the upper estuary had been decreasing. A slight upward trend occurred in the early 1960's

due to the provision of a higher degree of wastewater treatment. However, with increasing population, the amount of organic matter discharged has increased to a record high in 1970 resulting in a critical dissolved oxygen stress in the receiving water. In recent years, dissolved oxygen concentrations of less than 1.0 mg/l have occurred during low-flow, high-temperature periods.

13. Mathematical model simulation of the dissolved oxygen budget including carbonaceous, nitrogenous, benthic, and algal demands indicate that the nitrogenous demand is the greatest cause of dissolved oxygen deficit in the critical reach near the wastewater discharges and that algal growths have the greatest effect on DO from Piscataway to Indian Head, at times depressing it below 5.0 mg/l.

14. On the average, approximately 3-billion pounds per year of sediments enter the Potomac Estuary of which 2.2-billion pounds per year originate in the upper Potomac River Basin. The sediment yield from the Washington area on a lbs/sq mi/yr basis is about seven times greater than that from the upper basin.

15. Since 1913, the wastewater discharge quantities have increased over sevenfold from 42 to 325 mgd, the phosphorus load increased 22-fold from 1,100 to 24,000 lbs/day; nitrogen ninefold, from 6,400 to 60,000 lbs/day; and carbon approximately twofold, from 40,000 to 100,000 lbs/day. When ecological plant successions from a balanced toward an unbalanced system (primarily one dominated by blue-green algae) are related to wastewater loading trends, it can be concluded that the

ecological successions are the result of increases in nutrients. Moreover, it appears that the ecological changes are due primarily to the large increases in phosphorus and nitrogen.

16. In recent years, large populations of blue-green algae, often forming thick mats, have been observed in the Potomac Estuary from the Potomac River Bridge (Route 301) to the Woodrow Wilson Bridge during the months of June through October. In September of 1970, after a period of low-stream flow and high temperatures, the algal mats extended upstream beyond Hains Point and included the first nuisance growth within the Tidal Basin. The effects of the massive blue-green algal blooms in the middle and upper portions of the Potomac Estuary are (1) large increases of over 490,000 lbs/day in total oxygen demand, (2) an overall decrease in dissolved oxygen due to algal respiration in waters 12 feet and greater in depth, (3) creation of nuisance and aesthetically objectionable conditions, and (4) reduction in the feasibility of using the upper estuary as a potable water supply source because of potential toxin, taste, and odor problems.

17. To reduce the effects of excessive algal blooms on water quality and designated beneficial uses, it has been determined that during the summer months, the standing crop should be reduced to a minimum of 75 to 90 percent of the current level or to a chlorophyll a concentration at or below 25 ug/l.

18. From six independent methods of analysis, it appears that if the upper concentration limit of inorganic nitrogen is maintained between 0.3 and 0.5 mg/l as N and the upper limit of total phosphorus at

0.03 to 0.1 mg/l as P, the algal standing crop can be maintained below nuisance levels under summer conditions. The lower limits of nutrient concentration apply to the embayments and middle portion of the estuary where growing conditions are more favorable, whereas the higher concentrations are applicable to the upper portion of the estuary where lack of light penetration limits algal growth.

19. Significant accumulations of various heavy metals in sediments have been detected near the major wastewater discharges. A study of the possible long-term toxic effects of these heavy metals on the biota of the Potomac Estuary, especially shellfish, is essential.

20. Population and water supply needs have been projected as follows:

Year	Population	Water Supply Needs		
		Yearly avg. (mgd)	Maximum Month (mgd)	Maximum Daily (mgd)
1969	2,700,000	370	470	660
1980	4,000,000	570	720	1000
2000	6,700,000	1010	1310	1820
2020	9,300,000	1570	2040	2820

21. Even with the seven proposed upper Potomac River Basin reservoirs operational, the following withdrawals will be required from the estuary or from direct wastewater reuse to meet the water supply requirements:

Low-flow Characteristics Before Water Supply Diversion		Withdrawal from the Potomac Estuary or from Direct Reuse*		
		1980	2000	2020
Recurrence Interval (years)	Minimum Monthly Fresh Inflow (mgd)	For a 720 mgd Need (mgd)	For a 1310 mgd Need (mgd)	For a 2040 mgd Need (mgd)
5	1300	none	210	940
20	1170	none	340	1070
50	910	none	600	1330

* Withdrawal based on minimum 30-day low flow concurrently with a maximum 30-day water supply withdrawal and a 200 mgd minimum base flow over Great Falls into the estuary.

22. The projected wastewater volumes and loading characteristics before treatment are as follows:

Year	Flow (mgd)	BOD (lbs/day)	Nitrogen (lbs/day)	Phosphorus (lbs/day)
1969	325	483,500	63,500	27,300
1980	475	823,500	95,600	43,100
2000	860	1,463,500	155,700	70,300
2020	1,340	2,195,000	215,600	97,400

23. To aid in determining the allowable pollutant loadings from wastewater discharges, mathematical models have been developed and verified for predicting (1) phosphorus transport, (2) nitrogen transport and assimilation, (3) effects of benthic, carbonaceous, and nitrogenous oxygen demand, including the effects of algal photosynthesis

and respiration on the dissolved oxygen budget, and (4) chloride and total dissolved solid intrusions from the Chesapeake Bay, and their buildup as a result of water supply withdrawals from the estuary.

24. Based upon the study of projected wastewater quantities and the recently adopted metropolitan Washington wastewater treatment implementation schedule, the following can be concluded:

(1) Between the years 1980 and 2000, the Potomac (Dulles) Interceptor, with its current capacity of 65 mgd, will be overloaded.

(2) To provide for future wastewater collection and treatment facilities in areas currently projected to be served by the Potomac Interceptor, either the capacity of the interceptor would have to be significantly increased or additional wastewater treatment facilities constructed on the Potomac River above Washington.

(3) With the Blue Plains wastewater treatment capacity limited to 309 mgd, a need exists not only for one or more facilities to serve the Anacostia Valley but also to serve a portion of the upper Potomac area currently served by Blue Plains via the Dulles Interceptor.

(4) Large wastewater volumes are projected in the Occoquan and Pohick watersheds in the Virginia counties downstream from Washington, indicating a need for long-range water resources planning in this area.

25. Three basic alternative wastewater treatment systems were investigated to determine the effects of the discharge locations on

receiving water quality including chloride and total dissolved solid intrusions, as follows:

(1) Alternative I consisted of the following plants: Pentagon, Arlington, Blue Plains, Alexandria, Piscataway (also serving Andrews Air Force Base), Lower Potomac (serving Pohick, Accotink, Dogue, and Little Hunting Creek watersheds including Fort Belvoir), Mattawoman, Neabsco (serving the Occoquan watershed), and Port Tobacco.

(2) Alternative II consisted of the nine treatment plants as in Alternative I plus a facility serving the Anacostia Valley and located just above the Maryland-D. C. Line, and

(3) Alternative III consisted of the same facilities as Alternative II plus an upper Potomac plant discharging near Chain Bridge and serving the upper Potomac region.

Two other systems designated as Alternatives IV and V were also investigated. These were identical to III, except that for Alternative IV, all effluents were assumed to be discharged into the main channel of the Potomac; while for Alternative V, all effluents were assumed to be conveyed downstream to a common discharge point below Indian Head, Maryland.

26. Data from the chloride, total dissolved solids, and other simulations where the estuary was used as a potable water supply source indicate the following:

(1) The position of the salt wedge with respect to intrusion from the Chesapeake Bay is a function of (a) duration and magnitude

of any selected flow, (b) location of the wastewater treatment facility discharges, and (c) consumptive losses in the water distribution system.

(2) Even with no water supply withdrawals from the estuary, for comparable flow conditions, intrusion of chlorides and total dissolved solids from the Chesapeake Bay will occur farther upstream in the future as a result of the greater percentages of wastewater discharged downstream into the salt wedge and the projected increases in consumptive loss, with the latter having the most pronounced effect.

(3) The number of days during which the estuary can be used for water supply depends upon (a) the position of the wedge prior to the withdrawal, (b) magnitude of the withdrawal, (c) freshwater inflow during withdrawal, (d) location of the wastewater discharges, and (e) the increase in chlorides and total dissolved solids as a result of water use.

(4) The maximum possible number of days that the estuary could be used for a water supply source was determined by using a total dissolved solids concentration in the blended water of 500 mg/l maximum as a criterion since this parameter was determined to be more critical than chlorides. TDS water use increments* of 40 and 240 mg/l

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* Water use increment is the amount that the concentration of TDS or any other parameter is increased from the point of water intake to the point of discharge as a result of water supply treatment, municipal use, and wastewater treatment.

were applied at both the upstream and downstream location extremes of the saltwater wedge to give the results in the table below:

Alternative I
Maximum Days of Use of Estuary

Year	Water Withdrawal From Estuary (cfs)	Upper Position of Wedge Water Use Increment 40 mg/l	Upper Position of Wedge Water Use Increment 240 mg/l	Lower Position of Wedge Water Use Increment 40 mg/l	Lower Position of Wedge Water Use Increment 240 mg/l
1980	500	>166	>166	>166	>166
2000	1250	90	35	140	45
2020	2000	45	15	95	20

(5) For the year 2020 and using the upper position of the wedge (as observed in early September 1966--the lowest flow on record), the number of days that the estuary can be used as a water supply and yet maintain a maximum 500 mg/l total dissolved solids standard in the blended water is given below as a function of freshwater flow before water supply diversions:

Maximum Days of Use of Estuary

Freshwater Flow (cfs)	Alternative I Water Use Increment 40 mg/l (days	Alternative I Water Use Increment 240 mg/l (days)	Alternative V Water Use Increment 40 mg/l (days)	Alternative V Water Use Increment 240 mg/l (days)
400	45	15	18	18
1100	>166	42	>166	41
1800	>166	>166	>166	>166

(6) Since the projected water supply needs for the year 2020 cannot be met completely either by withdrawals from the estuary or

from the seven proposed upper basin reservoirs for drought periods extending over a month, both sources will eventually be needed to meet the future water requirements for the Washington metropolitan area. It appears that an increase of approximately 860 cfs (from 940 to 1800 cfs) in the Potomac River discharge at Washington will be required to maintain an acceptable blended water with respect to total dissolved solids for a 240 mg/l water reuse increase. If the increase is less than 240 mg/l, the flow regulation requirements will decrease.

(7) While other aspects of water supply requirements such as viruses and carbon chloriform extractables need to be considered in more detail, it appears that the estuary can be used as a supplementary water supply source if wastewater discharges and water supply withdrawals are subjected to adequate treatment.

27. Direct reuse of the renovated wastewater is another solution to meet water supply needs. This alternative has numerous advantages over withdrawals from the estuary because:

(1) Any need for consideration of salt intrusion from the Chesapeake Bay for water supply purposes is eliminated,

(2) Localized runoff and combined sewer overflows will not degrade the high quality renovated water,

(3) The need for flow regulation from upstream reservoirs to meet the projected Washington area water supply requirements is reduced to a total flow of approximately 1100 cfs (before water supply diversion) or an increase of about 150 cfs above unregulated conditions.

Excluding the psychological objections to treated wastewater reuse and the problems of physical transport of the wastewater to the water intake, the major disadvantage, especially from the technical viewpoint, would be the need to maintain the present maximum total dissolved solids buildup of 140 mg/l through the water supply treatment, water use, and wastewater renovation processes whenever more than 80 percent of the water supply is taken directly from renovated wastewater.

28. When the water resource needs of the entire basin are considered, the long-range solution to the water supply-wastewater disposal problem may initially be a combination of water supply withdrawals from the estuary and flow regulation, with direct reuse becoming increasingly feasible by early in the 21st Century.

29. The maximum allowable ultimate oxygen demand loadings have been determined as given below for various zones and subzones of the upper estuary for a 29°C temperature, a freshwater inflow after water supply diversion of 300 cfs, a DO of 6 mg/l in the treated effluent, and based upon maintaining 5 mg/l DO in the receiving waters.

MAXIMUM UOD LOADINGS FOR POTOMAC ESTUARY

Zone		Allowable UOD* (lbs/day)
I-a	(Upstream from Hains Point)	4,000
I-b	(Anacostia River)	3,000
I-c	(Hains Point to Broad Creek)	75,000
II	(Broad Creek to Indian Head)	190,000
III	(Indian Head to Smith Point)	380,000

* These loadings are the maximum allowable loadings for each zone assuming adjacent zones are loaded to their maximum capacities.

30. For the three freshwater inflows (before water supply withdrawal) investigated, i.e., 1800, 1100, and 400 cfs, the maximum UOD loadings were not affected significantly except for Alternative III which included a treated waste discharge in Zone I-a near Chain Bridge.

When the DO in the effluents in mathematical model simulations was decreased from 6.0 to 2.0 mg/l, the most pronounced effect was in Zone I-c in which the UOD loading decreased from 75,000 to 56,000 lbs/day.

31. Allowable UOD loadings for the Piscataway and Gunston Cove embayments have been developed for the projected wastewater volumes and conditions specified in Number 29 and are given below:

MAXIMUM UOD LOADINGS FOR PISCATAWAY CREEK AND GUNSTON COVE

Piscataway Creek		Gunston Cove	
Wastewater Flow (mgd)	Maximum UOD Load (lbs/day)	Wastewater Flow (mgd)	Maximum UOD Load (lbs/day)
24	10,000	50	7,000
49	11,000	103	11,000
79	12,000	170	16,000

32. Since nitrification (the conversion of ammonia nitrogen to nitrate nitrogen) has little effect on the oxygen resources of the estuary at temperatures below 15°C, nitrogen removal from the wastewater effluents to meet DO standards will be required whenever the water temperature is above 15°C, usually during the months of April through October.

In order to prevent formation of sludge deposits, to eliminate objectionable floating matter, and to prevent low DO concentrations during periods of ice cover, a minimum of 70-percent UOD removal and an effluent concentration of less than 15 mg/l suspended solids are required year-around for all discharges.

33. Using an average freshwater inflow of 300 cfs to the Potomac Estuary after water supply diversions, the allowable loadings of phosphorus by zones were determined based on maintaining an average maximum of 0.067 mg/l as P in Zones I and II, and 0.03 mg/l as P in Zone III for algal control. The allowable loadings are presented below:

MAXIMUM PHOSPHORUS LOADINGS FOR POTOMAC ESTUARY

Zone		Allowable Phosphorus (lbs/day)
I-a	(Upstream from Hains Point)	200
I-b	(Anacostia River)	85
I-c	(Hains Point to Broad Creek)	900
II	(Broad Creek to Indian Head)	1500
III	(Indian Head to Smith Point)	2000

34. Allowable phosphorus loadings for the Piscataway and Gunston Cove embayments for phosphorus concentration in the receiving waters of 0.03 mg/l as P are shown below as a function of wastewater flow:

PHOSPHORUS LOADINGS TO EMBAYMENTS

Piscataway Creek		Gunston Cove	
Wastewater Flow (mgd)	Maximum Phosphorus Load (lbs/day)	Wastewater Flow (mgd)	Maximum Phosphorus Load (lbs/day)
24	35	50	35
49	50	103	60
79	65	170	140

35. To prevent excessive algal growth and to enhance the water quality in the upper and middle reaches of the estuary, it appears that it will be necessary to remove phosphorus on a continuous or a year-around basis for discharges into the upper estuary. Moreover, the control of at least 50 percent of the phosphorus load originating in the upper Potomac River Basin appears necessary if the aforementioned phosphorus criteria are to be achieved. To accomplish this reduction, the current phosphorus loading from all wastewater discharges in the upper Potomac River Basin must be decreased from 6100 to 700 lbs/day.

36. Using a freshwater inflow of 300 cfs and average maximum inorganic nitrogen concentrations of 0.5, 0.4, and 0.3 mg/l in Zones I, II, and III, respectively, for algal control, the maximum nitrogen loadings for warm temperature conditions were determined as follows:

NITROGEN LOADINGS FOR POTOMAC ESTUARY

Zone		Allowable Total Nitrogen (lbs/day)
I-a	(Upstream from Hains Point)	1000
I-b	(Anacostia River)	300
I-c	(Hains Point to Broad Creek)	3400
II	(Broad Creek to Indian Head)	5800
III	(Indian Head to Smith Point)	9000

37. Allowable total nitrogen loadings for the Piscataway and Gunston Cove embayments based upon maintaining 0.3 mg/l of inorganic nitrogen under warm temperature conditions and for varying wastewater flows follow:

NITROGEN LOADINGS TO EMBAYMENTS

Piscataway Creek		Gunston Cove	
Wastewater Flow (mgd)	Maximum Nitrogen Load (lbs/day)	Wastewater Flow (mgd)	Maximum Nitrogen Load (lbs/day)
24	120	50	130
49	170	103	270
79	270	170	460

38. Considering the present difficulty in controlling nitrogen in the upper basin and its transport characteristics in the estuary, it appears that the need for nitrogen removal for algal control at wastewater treatment plants will be limited to those periods when the water temperature exceeds 15°C, normally from April through October. With the large projected increases in nitrogen from wastewater discharges, there may be a need for year-around nitrogen control by the year 2000.

39. Because of the lack of transport and assimilative capacity in the upper portions of small tidal embayments and also because of ideal algal growing conditions, maximum concentrations of UOD, phosphorus and nitrogen in effluents discharged to these areas should be less than 10.0, 0.2, and 1.0 mg/l, respectively. A detailed analysis for each embayment is required to determine the minimum cost of either extending the discharge outfall to the main channel of the Potomac or discharging within the embayment and providing a very high degree of wastewater treatment, approaching ultimate wastewater renovation. Unless this high degree of removal is provided, effluents from Alexandria, Arlington, Piscataway, and the Lower Potomac facilities should be discharged into the main channel of the Potomac Estuary.

40. The present worth cost of additional wastewater treatment from the year 1970 to 2020, including operation, maintenance, and amortization costs, has been estimated to be $1.34 billion with a total average annual cost of $64.8 million. The unit treatment processes assumed include activated sludge, biological nitrification-denitrification, lime clarification, filtration, effluent aeration, and chlorination.

41. The cost of wastewater treatment on a per capita basis is as follows:

Item	1970-1980	1980-2000	2000-2020
Average Population	3,350,000	5,350,000	8,000,000
Initial Capital Cost/Person/Year	$17.0	$ 4.90	$ 7.30
Operation and Maintenance Cost/Person/Year	$ 7.50	$ 8.60	$ 9.10
Total Cost/Person/Year	$24.50	$13.50	$16.40

CHAPTER III

STUDY AREA DESCRIPTION

A. POTOMAC RIVER TIDAL SYSTEM

The Potomac River Basin, with a drainage area of 14,670 square miles, is the second largest watershed in the Middle Atlantic States. From its headwaters on the eastern slope of the Appalachian Mountains, the Potomac flows first northeasterly then generally southeasterly in direction some 400 miles to the Chesapeake Bay.

Above Washington, D. C., the Potomac traverses the Piedmont Plateau to the Coastal Plain at the Fall Line. Below the Fall Line, the Potomac is tidal and extends 114 miles southeastward to its discharge point into the Chesapeake Bay.

The tidal portion is several hundred feet in width at its uppermost reach near Washington and broadens to nearly six miles at its mouth. A shipping channel with a minimum depth of 24 feet is maintained upstream to Washington. Except for this channel and a few short reaches with depths up to 100 feet, the tidal portion is relatively shallow with an average depth of about 18 feet.

The mean tidal range is about 2.9 feet in the upper portion near Washington and about 1.4 feet near the Chesapeake Bay. The lag time for the tidal phase between Washington and the Chesapeake Bay is about 6.5 hours.

Of the 3.3 million people living in the entire basin, approximately 2.8 million reside in the Washington metropolitan area. The remaining area of the tidal portion, which drains 3,216 square miles, is sparsely populated.

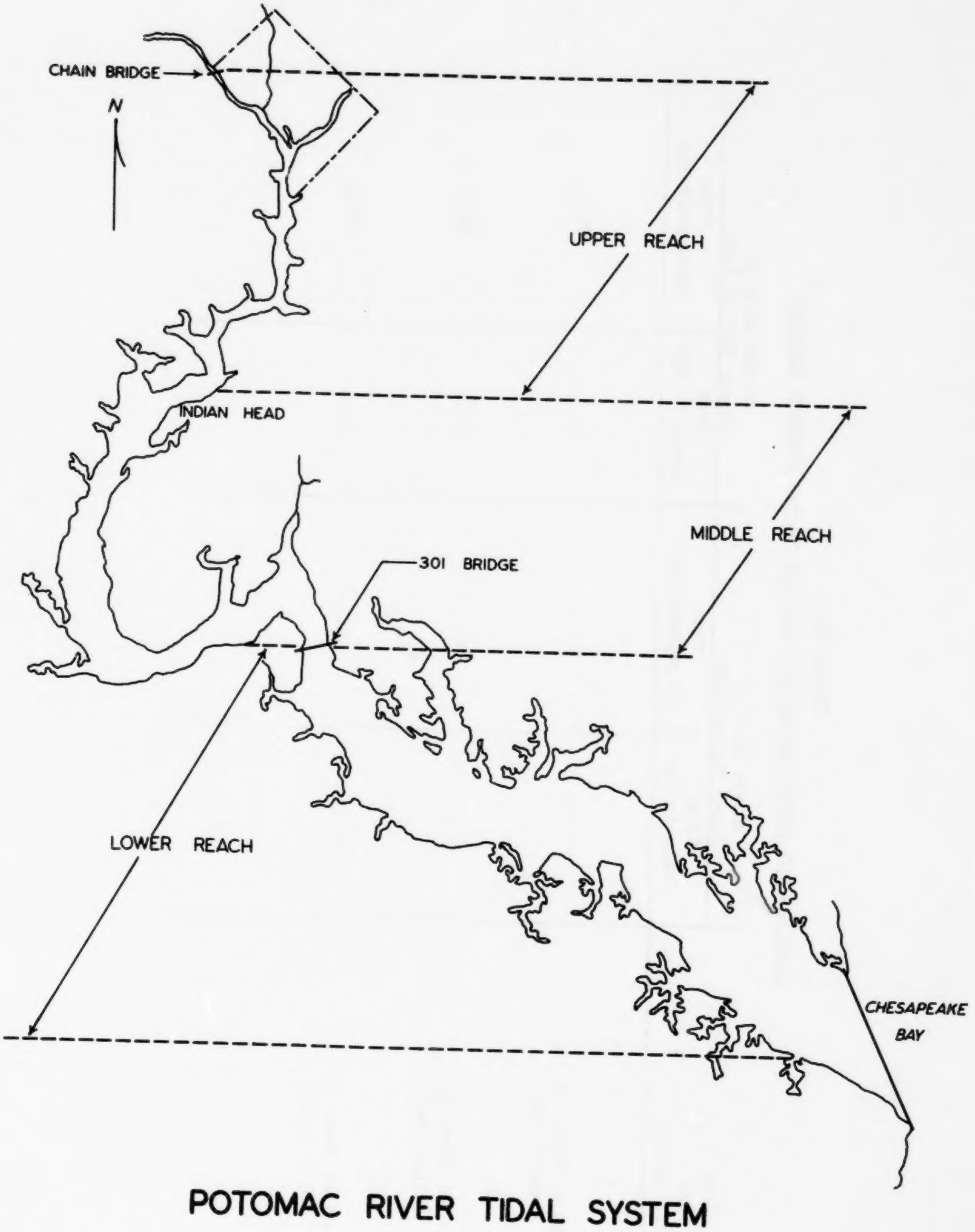
For purposes of discussion and investigation, the tidal portion of the Potomac River has been divided into three reaches as shown in Figure III-1 and described below:

Reach	Description	River Mile	Volume cu.ft.x10^9
Upper	From Chain Bridge to Indian Head	114.4 to 73.8	9.3
Middle	From Indian Head to Rte. 301 Bridge	73.8 to 47.0	36.2
Lower	From Rte. 301 Bridge to Chesapeake Bay	47.0 to 00.0	175.4

The upper reach, although tidal, contains fresh water. The middle reach is normally the transition zone from fresh to brackish water. The lower reach is saline with chloride concentrations near the Chesapeake Bay ranging from about 7,000 to 11,000 mg/l.

To facilitate determination of water quality control requirements, the upper and middle reaches of the estuary have been segmented into 15-mile zones of similar physical characteristics beginning at Chain Bridge.

River mile distances from both the Chesapeake Bay and Chain Bridge for the three upper zones are given in Table III-1. This zone concept was adopted by the conferees at the Potomac Enforcement Conference on May 8, 1969.


CHAIN BRIDGE
N
UPPER REACH
INDIAN HEAD
MIDDLE REACH
301 BRIDGE
LOWER REACH
CHESAPEAKE BAY

POTOMAC RIVER TIDAL SYSTEM

FIGURE III-1

Table III-1

ZONES OF THE UPPER AND MIDDLE REACHES OF THE POTOMAC ESTUARY

Zone and Description	River Mile of Upper End of Zone		River Mile of Lower End of Zone	
	from Chain Bridge	from Chesapeake Bay	from Chain Bridge	from Chesapeake Bay
I Chain Bridge to Broad Creek	0.0	114.4	15.0	99.4
II Broad Creek to Indian Head	15.0	99.4	30.0	84.4
III Indian Head to Smith Point	30.0	84.4	45.0	69.4

B. HYDROGRAPHIC ANALYSIS

The major source of freshwater inflow into the Potomac Estuary is from the upper Potomac River Basin. The average flow, measured at Great Falls before diversions for municipal water supply for the period from 1930-1968, was 10,768 cfs with a minimum flow of 610 cfs that occurred on September 10, 1966.

The monthly flow characteristics for the Potomac at Great Falls are tabulated below for the reference period of 1931-1960.

Month	25 Percent Quartile	Mean Flow (cfs)	75 Percent Quartile
January	7,600	13,600	17,200
February	8,700	16,600	24,600
March	13,900	21,100	24,400
April	12,800	20,000	26,900
May	8,800	14,500	17,900
June	6,100	8,700	10,300
July	3,500	5,500	6,400
August	2,700	6,000	7,400
September	2,000	4,700	6,800
October	2,000	6,300	6,400
November	3,000	6,600	9,600
December	3,800	9,900	13,100

In water resource management, especially for the water quality aspects, low-flow frequencies are used to determine assimilation and transport capacities of receiving waters. The low-flow frequency utilized for water quality control in the Potomac Estuary as set by the State of Maryland and the District of Columbia is the seven-consecutive-days-of-low-flow with a recurrence interval of once-in-10-years. For the Potomac at Washington, this is 954 cfs (before the diversions for water supply). See Table III-2 for complete analyses of low-flow frequency information.

Table III-2
MAGNITUDE AND FREQUENCY OF LOW FLOWS
POTOMAC RIVER NEAR WASHINGTON, D. C.
1930-1966 WATER YEARS
(Before Water Supply Diversions)

Period	Discharge for indicated recurrence interval					
	1.02 years	2.0 years	5.0 years	10.0 years	20.0 years	50.0 years
(Consecutive days)	(cfs)					
7	3,440	1,620	1,150	954	814	670
14	3,850	1,700	1,210	1,000	862	730
30	4,470	1,890	1,340	1,130	976	840
60	6,620	2,300	1,540	1,260	1,070	900
90	8,630	2,660	1,740	1,420	1,210	1,000
120	8,770	3,110	2,060	1,670	1,400	1,150
183	11,200	4,280	2,800	2,220	1,830	1,480

C. PROPOSED RESERVOIR DEVELOPMENT

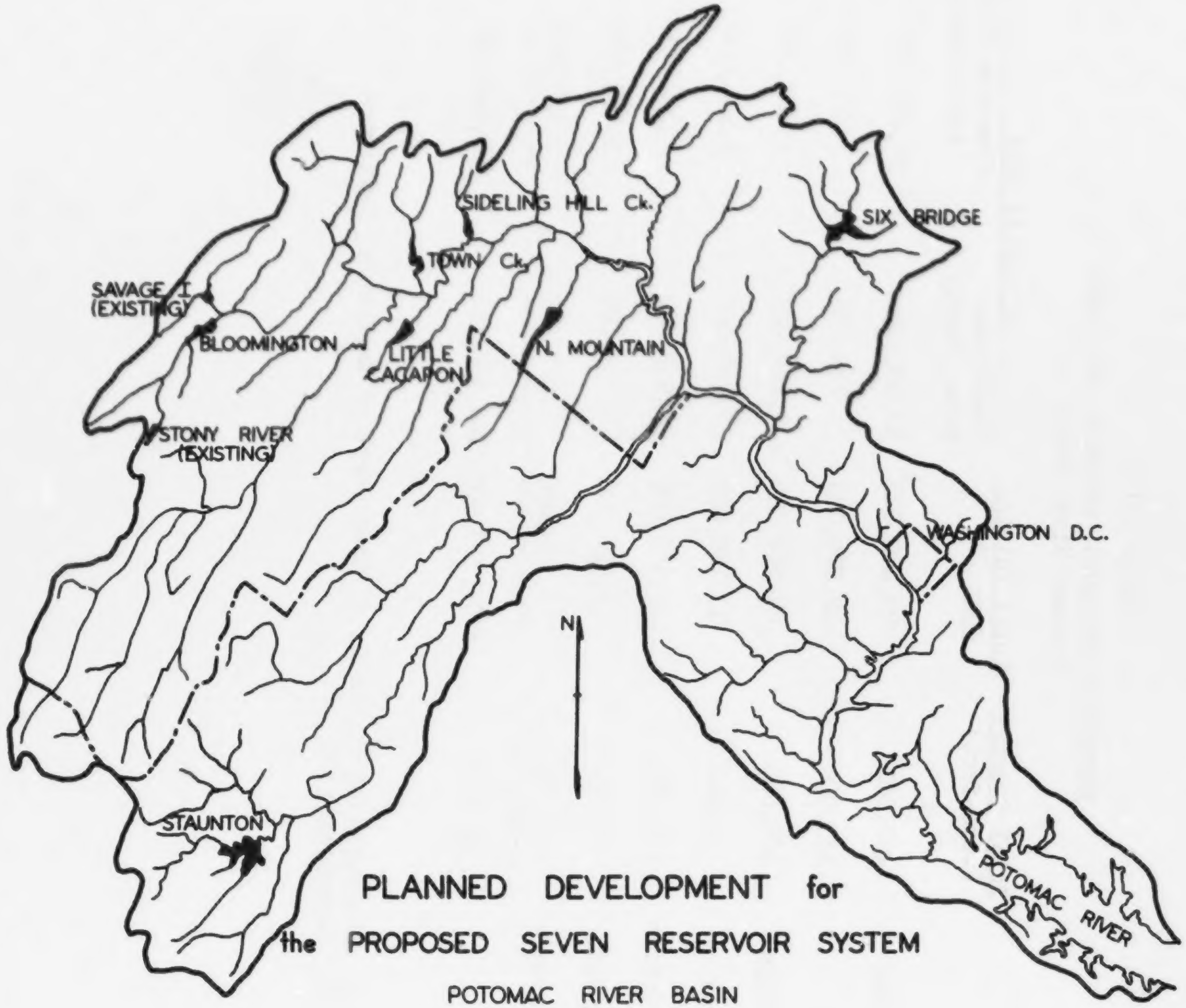
In 1956, the U. S. Army initiated a study of the water resources of the Potomac River Basin. The result of this study was a plan for development of water and related land resources of the basin including (1) water supply, (2) water quality, (3) flood control, and (4) recreational needs.

The plan recommended a 16-reservoir system to provide for orderly development, conservation, and utilization of the basin water resources to meet the needs of the next 50 years [1]. To provide additional water supply resources for the Washington metropolitan area, three alternative reservoir systems were suggested. These three systems were:

System	
I	Bloomington
II	Bloomington, Verona, and Sixes Bridge
III	Bloomington, Verona, Sixes Bridge, Town Creek, North Mountain, Sideling Hill, and Little Cacapon

The locations of the seven reservoirs in System III plus the two existing impoundments are shown in Figure III-2. The initial cost of the seven impoundments based on the 1967 cost index would be $204.4 million. See Table III-3 for individual reservoir cost.

Using data from 1929 to 1968 and a river-flow mathematical model, the U. S. Army Corps of Engineers simulated the effects of the three reservoir systems on river flows over Great Falls. The low-flow frequency analysis for the three systems is given in Table III-4.


SIDELING HILL Ck.
SIX BRIDGE
TOWN Ck.
SAVAGE I (EXISTING)
BLOOMINGTON
LITTLE CACAPON
N. MOUNTAIN
STONY RIVER (EXISTING)
WASHINGTON D.C.
N
STAUNTON
POTOMAC RIVER

PLANNED DEVELOPMENT for
the PROPOSED SEVEN RESERVOIR SYSTEM
POTOMAC RIVER BASIN

FIGURE III - 2

Table III-3

RESERVOIR PROJECTS, STORAGE, AND COST*
Potomac River Basin

Project	Total Storage (acre-feet)	Total Initial Cost ($)	Allocated Cost: Downstream Water Supply ($)	Allocated Cost: Preserve Stream Environment
Bloomington	137,500	90,400,000	30,000,000	36,800,000
Staunton	143,000	22,870,000	756,000	3,473,000
Sixes Bridge	103,000	20,510,000	1,112,000	5,005,000
Town Creek	96,800	13,190,000	2,039,000	4,136,000
North Mountain	195,000	24,450,000	3,953,000	7,312,000
Sideling Hill	75,000	13,600,000	2,753,000	5,557,000
Little Cacapon	82,500	19,350,000	3,872,000	7,857,000
Total	832,800	$204,370,000	$44,485,000	$70,140,000

* Based on data supplied by the U. S. Army Corps of Engineers, Baltimore District, September 1970

Table III-4

LOW-FLOW FREQUENCY ANALYSES FOR VARIOUS RESERVOIR SYSTEMS
Potomac River near Washington

Reservoir System

Period (days)	Discharge in cfs for Indicated Recurrence Interval (5 years)	(10 years)	(50 years)
	Number I		
30	1600	1200	1000
60	1900	1600	1050
90	2100	1700	1100
120	2600	2000	1500
	Number II		
30	1900	1700	1200
60	2000	1900	1400
90	2200	2100	1500
120	2600	2200	1600
	Number III		
30	2000	1800	1400
60	2150	2000	1500
90	2300	2200	1600
120	2800	2300	1700

D. WATER RESOURCE USES

1. Water Supply Use

a. Municipal

The municipal water supply needs of the Washington metropolitan area are obtained from five major sources. The largest source is the Potomac River above Washington, D. C. For 1969-1970, water withdrawal data for the five sources are presented below:

Source	Withdrawal (mgd)
Potomac River above Great Falls	265
Patuxent River near Laurel	46
Goose Creek	6
Occoquan Creek	42
Wells and other minor sources	11
Total	370

Currently, there is no municipal water withdrawn from the freshwater portion of the Potomac Estuary. However, during the drought in the summer of 1969, an emergency estuary intake would have been constructed and used had the lows flows continued.

b. Industrial

In the Washington metropolitan area, the amount of water used for manufacturing is insignificant. The major industrial use is as cooling water.

There are currently six major cooling water users in the Potomac River tidal system with another being proposed near Sandy Point. The total cooling water use is 2,748 mgd as follows:

Facility	Water Usage (mgd)	Receiving Water	Remarks
PEPCO at Benning Rd. (Washington, D. C.)	568	Anacostia River	Also Uses Cooling Towers
PEPCO, Buzzard Point (Washington, D. C.)	570	Anacostia River	
Virginia Heating (Arlington, Va.)	40	Boundary Channel of Potomac Estuary	
PEPCO Generating Station (Alexandria, Va.)	450	Potomac Estuary	
VEPCO, Possum Point (Quantico, Va.)	400	Potomac Estuary	
PEPCO, Sandy Point	--	Potomac Estuary	Proposed Facility
PEPCO, Morgantown (Charles Co., Md.)	720	Potomac Estuary	Ultimate Usage to be 1440 mgd
Total	2,748		

Navigational use of the Potomac Estuary waters is primarily to provide commercial transport via river barges. Two commercial firms presently transport various petroleum products from tank farms located in the lower Potomac and in the Chesapeake Bay proper to the Washington metropolitan area.

Sand and gravel mining is also a water related industrial use of the estuary bed. Currently, dredging for this purpose is being conducted in the estuary below Indian Head, Maryland.

2. Recreation and Boating

Aside from enhancing the suburban environment, the water and land resources of the Potomac Estuary and its tributaries contribute to the aesthetics of the nation's capital. From Washington, where large numbers of tourists visit the numerous monuments, museums, public buildings, and parks, to the remote park at Point Lookout near the Chesapeake Bay, the Potomac's amenities are widely used. These include freshwater and tidal sport fishing, boating, hunting, swimming, camping, and picnicking.

At the present time, there are approximately 95 marina facilities in the Potomac River tidal system. These marinas offer slips and moorings to accommodate over 5,200 recreational watercraft. They also provide boat rentals and launching areas for small craft.

Expanses of open water below Washington with large populations of several popular species have stimulated the growth of sport fishing in the Potomac Estuary. A study in 1959-1961, estimated that 101,000 angler trips produced approximately 1,200,000 fish weighing almost 642,000 pounds [2].

The most popular fish caught are striped bass, bluefish, spot, and perch. For a 5-month period during the 1961 survey, an estimated $594,000 was spent by Potomac Estuary anglers [2].

A recent study by the Bureau of Outdoor Recreation indicated the following regarding recreational facilities and the potential of the Potomac Estuary [3]:

1. Of the 637 miles of shoreline and 207,000 acres of water surface, which are rich in natural resources, the recreational potential has barely been touched.

2. At the present time, there is one national park, three state parks, three state forests, seven game and fish areas, and 226 county recreation sites in the estuary drainage area. Most of these areas are located inland without direct access to the water.

3. The recreational potential remains relatively undeveloped because of poor access to many shoreline areas and because extensive acreage is controlled by private and government interests.

4. There are few public beaches, but lack of such development is probably due more to poor water quality and the hazard of stinging jellyfish than to a lack of suitable locations.

3. Commercial Fisheries

The Potomac River tidal system supports a substantial commercial fishery. There are approximately 160 species in the Potomac Estuary ecosystem of which the anadromous* and the semi-anadromous** species such as striped bass, shad, white and yellow perch, winter flounder, and herring are the most significant economically.

Another group of commercially important fish species spawns and winters outside of the Chesapeake Bay in the Atlantic Ocean and utilizes the Potomac for a nursery area and feeding ground. Included in this group are the menhaden, croaker, silver perch, sea trout, and drum.

Cysters are indigenous to the lower reaches of the Potomac Estuary. These reaches are considered prime shellfish waters.

Soft clams, like oysters, are indigenous to the Chesapeake Bay and occur in the same general areas. Only in recent years, however, have they been harvested commercially and the resource far exceeds the demand.

The lower Potomac is a favorable habitat for the growth of blue crabs. As juveniles, the young crabs feed and grow in the estuary before completing their life cycle at the mouth of the Chesapeake Bay.

* Anadromous - fish which spend most of their lives in the ocean and ascend freshwater streams and rivers to spawn

** Semi-anadromous - fish which spend most of their lives in a brackish water and ascend freshwater streams to spawn

In 1969, approximately 9 million pounds of fish, 1.9 million pounds of crabs, 1.4 million pounds of clams, and 5.3 million pounds of oysters were harvested from the waters of the Potomac and its tributaries [4]. The dockside value of the 1969 harvest was computed to be over $4.6 million. See Table III-5.

There are currently about 29,000 acres of oyster beds in the Potomac Estuary and its embayments. Of these, approximately 970 acres, mainly in the embayments, are closed because of high bacterial densities resulting from domestic sewage pollution.

Numerous fish kills have occurred in the Potomac Estuary in recent years. While the cause of many of these kills is unknown, several have been attributed to low dissolved oxygen concentrations resulting from domestic waste discharges such as the large kill near Washington during May 1969.

Table III-5

MARYLAND AND VIRGINIA LANDINGS OF FISH AND SHELLFISH
POTOMAC RIVER AND TRIBUTARIES
1969

Species	Maryland		Virginia		Total	
	Pounds	Value	Pounds	Value	Pounds	Value
Fish	1,250,668	$ 183,563	7,780,549	$ 347,974	9,031,217	$ 531,537
Crabs -						
Hard	628,702	75,686	1,249,774	142,460	1,878,476	218,146
Soft & Peeler	20,348	8,260	28,000	11,659	48,348	19,919
Clam	1,090,140	389,292	322,092	114,331	1,412,232	503,623
Oyster	2,923,275	1,771,812	2,457,770	1,642,866	5,381,045	3,414,678
Total	5,913,133	$2,428,613	11,838,185	$2,259,290	17,751,318	$4,687,903

CHAPTER IV

WASTEWATER LOADINGS AND RUNOFF CONTRIBUTIONS

A. WASTEWATER LOADINGS AND TRENDS

In the upper reach from Great Falls to Indian Head, Maryland, a domestic wastewater flow of approximately 325 mgd is discharged into the Potomac River tidal system. Eighteen facilities currently serve approximately 2.5 million people in the Washington metropolitan area with the largest facility being the Blue Plains Plant of the District of Columbia (Table IV-1). Of the 325 mgd, 41.5, 23.1, and 35.4 percent come from Maryland, Virginia, and the District of Columbia respectively.

An analysis of the loading trends since 1913 indicates that wastewater volumes have increased eightfold, from 42 to 325 mgd. Similar trends have occurred for total nitrogen and phosphorus with 10-fold and 24-fold increases respectively (Table IV-2).

Of major significance has been the increase in ultimate oxygen demand (UOD) loadings. The carbonaceous UOD increased from 84,000 lbs/day in 1913 to about 297,000 lbs/day in the late 1950's. With the construction of the secondary treatment facilities, including completion of the Blue Plains Plant of the District of Columbia, the carbonaceous loading was reduced to 110,000 lbs/day. The nitrogenous loading has increased steadily from 1913 to the present loading of 254,000 lbs/day, which exceeds the current carbonaceous loading of 204,000 lbs/day.

Table IV-1

WASTEWATER LOADINGS TO THE UPPER POTOMAC ESTUARY AND TRIBUTARIES
GREAT FALLS TO INDIAN HEAD 1970

Facility	Population Served	Flow	BOD$_5$		Suspended Solids		T. Phosphorus as P	TKN	NO$_2$ + NO$_3$
		mgd	Untreated (lbs/day)	Treated (lbs/day)	Untreated (lbs/day)	Treated (lbs/day)	Treated (lbs/day)	Treated (lbs/day)	Treated (lbs/day)
Pentagon	10,600*	1.060	2,100	360	2,100	310	65	290	20
Arlington	247,000	19.390	33,500	5,460	37,400	14,300	1,650	1,020	1,465
Sewer Overflows D. C. System	18,300**	2.516	3,740	3,740	3,700	3,700	170	460	20
Naval Laboratory White Oaks, Md.	950*	0.095	25	7	32	12	7	25	1
District of Columbia	1,830,000	251.660	373,700	103,800	369,900	102,000	17,300	46,200	2,000
Alexandria	190,000	23.300	38,000	13,000	36,200	12,600	2,300	3,690	20
Fairfax-Westgate	124,400	11.570	11,500	10,900	9,600	8,200	1,280	1,830	40
Piscataway, WSSC	55,000	5.810	6,300	540	7,300	1,310	320	630	100
Andrews AFB No. 1	8,200*	0.820	1,200	110	770	110	45	50	30
Andrews AFB No. 4	860*	0.086	104	16	80	10	5	3	3
Naval Comm. Station Cheltenham, Md.	670*	0.067	110	15	140	14	3	2	1
Fairfax-Hunting Cr.	25,000	3.260	4,060	1,390	3,880	1,130	380	620	15
Fairfax-Dogue Cr.	20,000	2.441	4,048	915	4,010	760	270	365	20
Fort Belvoir No. 1	3,600	0.600	1,100	120	110	70	30	25	25
Fort Belvoir No. 2	18,400	2.340	3,500	380	3,800	325	175	430	20
Fairfax-Lower Potomac****	-	-	-	-	-	-	-	-	-
Naval Ordnance Station Indian Head, Md.									
Site I	2,500*	0.250	155	90	200	160	12	25	1
Site II	3,600*	0.360	355	140	430	80	8	5	1
Site III	60*	0.006	2	1	2	1	1	1	1
Site IV	10*	0.001	2	1	2	1	1	1	1
TOTAL		325.632	483,501	140,985	479,656	145,093	24,022	55,672	3,784

* Based on 100 gcpd
** Based on dry weather flow to wastewater facility
*** Under construction

Table IV-2
WASTEWATER LOADING TRENDS
WASHINGTON METROPOLITAN AREA

Year	Population Served	Flow[1] (mgd)	Untreated 5-Day BOD (lbs/day)	Removal 5-Day BOD %	Treated 5-Day BOD (lbs/day)	Ultimate[2] Car. BOD (lbs/day)	Ultimate[4] Nit. BOD (lbs/day)	Total Ultimate BOD (Car.+ Nit.) (lbs/day)	Total Nitrogen (lbs/day)	Total Phos. as P (lbs/day)
1913	320,000	42	58,000	0	58,000	84,000	29,000	113,000	6,400	1,100
1932	575,000	75	103,000	0	103,000	149,000	52,000	201,000	11,400	2,000
1944	1,149,000	167	235,000	40	141,000	205,000	105,000	310,000	23,000	4,000
1954	1,390,000	195	280,000	28	200,000	290,000	145,000	435,000	31,700	5,500
1957	1,680,000	210	305,000	33	204,000	297,000	153,000	450,000	33,500	8,600
1960	1,860,000	222	370,000	70	110,000	160,000	170,000	330,000	37,200	10,000
1965	2,100,000	285	417,000	70	125,000	182,000	192,000	384,000	42,000	18,800
1968	2,415,000	319	428,000	70	130,000	188,000	226,000	414,000	50,000	20,100
1969	2,480,000	320	439,000	71	129,000	186,000	222,000	408,000	55,000	21,100
1970	2,535,000	322	484,000	71	141,000	204,000	254,000	456,000	60,000	24,000

1. Includes estimated sewer overflow loadings

2. Ultimate carbonaceous BOD = 1.45 x 5-day BOD

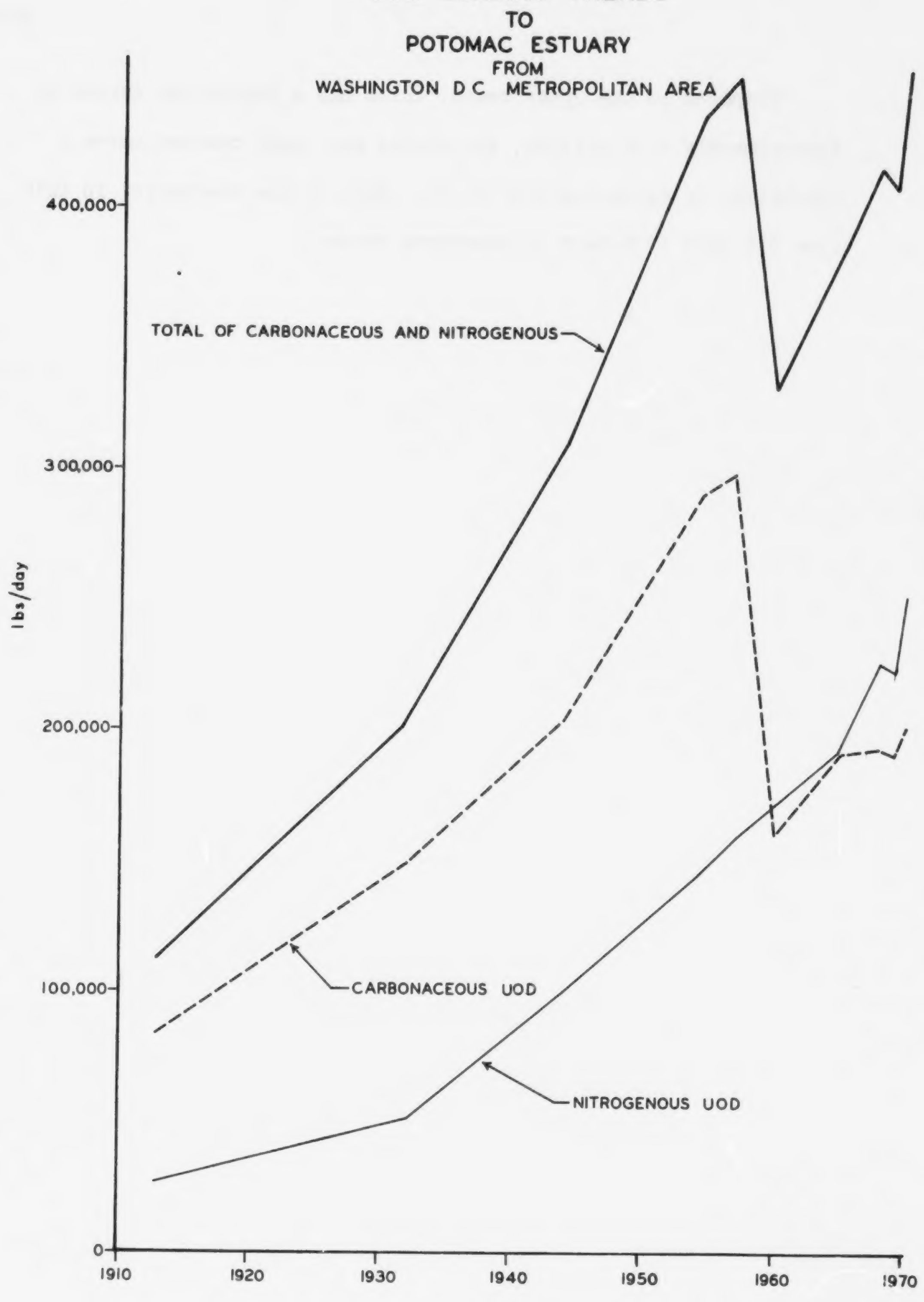
3. Ultimate nitrogenous BOD = 4.57 x unoxidized nitrogen

As can be seen in Figure IV-1, the current total oxygen demanding carbonaceous and nitrogenous loading is over 450,000 lbs/day, the highest loading rate ever discharged into the estuary although the percent removal of 5-day BOD has remained at about 70 percent. Since 1960, the increase in wastewater volumes and the continual increase in nitrogenous UOD has resulted in a total oxygen demanding load to the estuary similar to that which occurred before the secondary treatment facility at Blue Plains was completed in the late 1950's.

There are 82 wastewater point source discharges into the middle and lower reaches of the Potomac Estuary and their tributaries. The estimated BOD, total phosphorus as P, and nitrogen as N are 4,000, 500, and 1,000 lbs/day, respectively.

The major sources of domestic wastewater discharges are listed below:

	Wastewater Volume (mgd)	Receiving Water
Mannassas Park No. 1	0.109	Bull Run
Mannassas Park No. 2	0.221	Bull Run
Manassas	0.786	Bull Run
Greenbrier	0.214	Bull Run
Fairfax-Flatlick	0.111	Flatlick Run
Greater Manassas S. D.	0.700	Bull Run
Lorton Reformatory	0.410	Giles Run
Marumsco	1.000	Marumsco Creek
Featherstone, Va.	0.300	Farm Creek
Marine Corps Schools (Quantico, Va.)	1.400	Potomac Estuary
Naval Weapons Laboratory (Dahlgren, Va.)	0.350	Upper Machodoc Creek



UOD LOADING TRENDS
TO
POTOMAC ESTUARY
FROM
WASHINGTON D C METROPOLITAN AREA

FIGURE IV-1

Compared to the upper reach, which has a population served of approximately 2.51 million, the middle and lower reaches serve a population of approximately 50,000. Most of the discharges in this area are into tributary or embayment waters.

B. POTOMAC RIVER WATER QUALITY ABOVE GREAT FALLS

Detailed analyses of the freshwater inflow from the upper Potomac River Basin at Great Falls were conducted during 1969 and 1970. During the period of February 1969 to February 1970, the following were the average measured concentrations of BOD_5 and nutrients:

Parameter	Concentration (mg/1)
BOD_5	2.60
TKN as N	0.61
$NO_2 + NO_3$ as N	1.00
T. Phosphorus as P	0.13

The observed data, as shown in Figure IV-2, show the wide range of nutrient concentrations for the period of June 1969 to July 1970. The river discharge was considerably higher during the 6 months of 1970 than for the last 7 months of 1969. This resulted in higher $NO_2 + NO_3$ concentrations. Concentrations of TKN and phosphorus appeared to decrease during the higher flow periods except during periods of intense runoff [5].

The contributions from the upper basin in lbs/day during the period of February 1969 through February 1970 are presented in Table IV-3. For the 13-month period, the average daily contributions of nutrients were tabulated and are given below:

Parameter	Contribution (lbs/day)
T. Phosphorus as P	4,580
Inorganic Phosphorus as P	2,650
TKN as N	22,410
NH_3 as N	4,590
$NO_2 + NO_3$ as N	36,700

NUTRIENT CONCENTRATIONS
POTOMAC RIVER AT GREAT FALLS

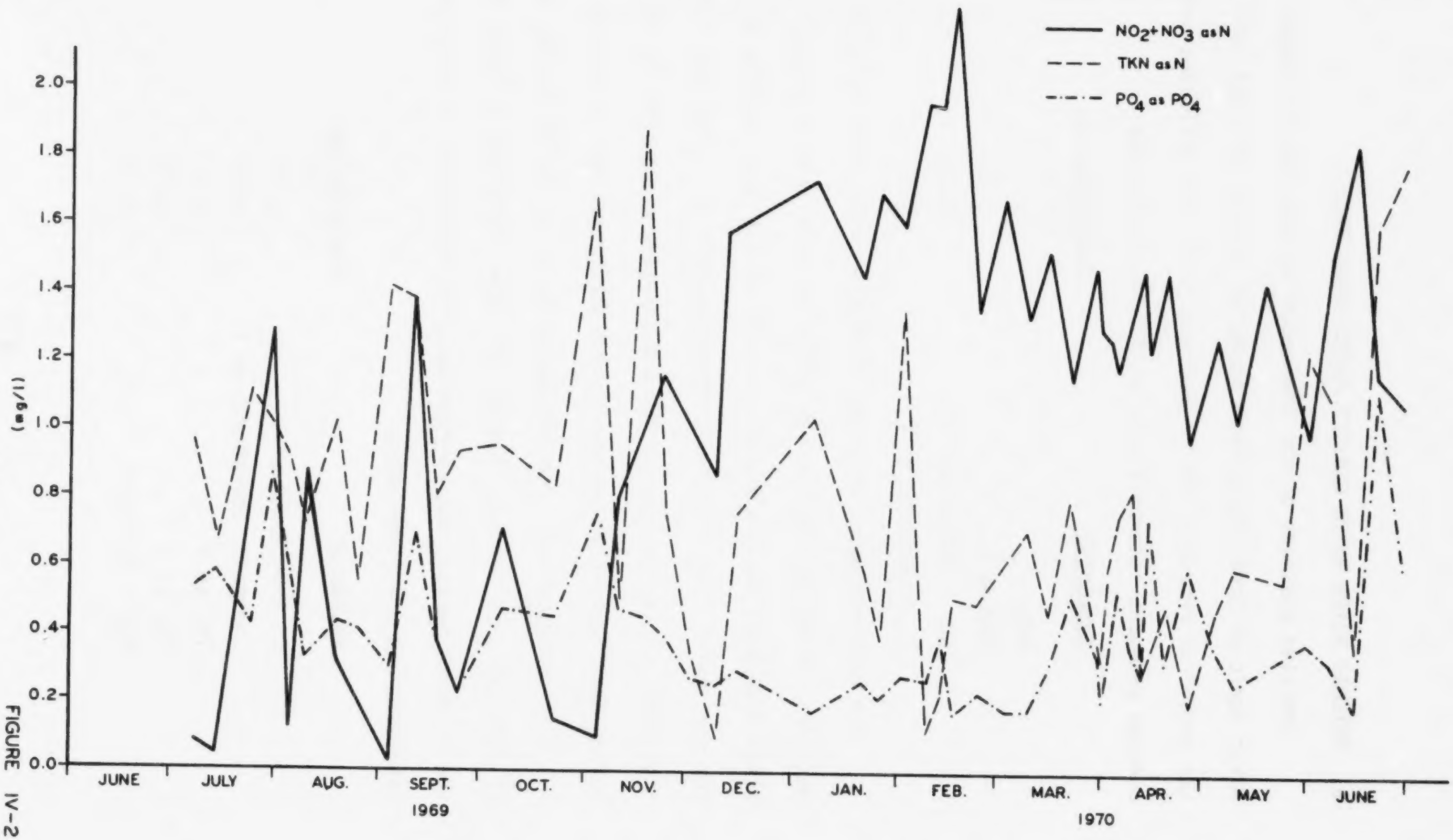


FIGURE IV-2

Table IV-3

UPPER POTOMAC RIVER BASIN CONTRIBUTIONS
(Above Great Falls)
February 1969 through February 1970

Month	Flow (cfs)	T. Phosphorus as P (lbs/day)	Inorganic Phosphorus as P (lbs/day)	TKN as N (lbs/day)	NH_3 as N (lbs/day)	$NO_2 + NO_3$ as N (lbs/day)
February	6,700	4,495	2,070	22,180	4,670	23,080
March	8,400	5,500	3,270	26,360	5,300	45,370
April	7,000	4,740	2,120	22,700	5,080	21,750
May	3,900	2,730	900	11,680	3,750	7,910
June	2,200	1,560	430	7,630	2,070	2,890
July	2,400	1,700	540	8,460	2,190	4,970
August	8,000	5,310	2,700	26,260	5,290	32,030
September	4,300	2,920	1,050	14,680	3,370	10,040
October	2,300	1,680	420	8,200	2,240	3,160
November	3,600	2,540	810	11,800	3,070	6,980
December	7,900	5,230	2,980	25,890	5,100	39,400
January	11,900	7,830	5,600	38,870	6,950	86,980
February	21,400	13,360	11,550	66,610	10,590	191,910
Average	6,900	4,580	2,650	22,410	4,590	36,700

A regression analysis of the river discharge and contribution loadings was made. Utilizing the flow duration curve for the Potomac River near Washington and the regression equation between river discharge and loadings, the contribution of phosphorus, nitrogen, and BOD_5 was determined for three frequency periods: 5%, 50%, and 95% of the time (Table IV-4). Based on this analysis, 50 percent of the time, which corresponds to a median river discharge of 6,470 cfs, the nutrient loadings into the Potomac from the upper basin are as follows:

Parameter	Median Loading (lbs/day)
BOD_5	89,390
TKN as N	16,850
NO_2 + NO_3 as N	19,830
Phosphorus as P	4,350
Total Carbon as C	480,000

Data for the 5-percent duration or 34,000 cfs, as also given in Table IV-4, show higher loading rates and thus higher total loadings. Conversely, for the 95-percent duration of the 1200 cfs discharge rate, the loading rates are lower as are the loadings. For water quality control purposes, the 50- and 95-percent duration times are more applicable since they occur under critical summer conditions.

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* Frequency percent is percentage of time in which a given parameter is equalled or exceeded

Table IV-4

NUTRIENT AND BOD CONTRIBUTIONS FROM THE UPPER POTOMAC RIVER BASIN
ABOVE GREAT FALLS, MARYLAND
(Drainage Area = 11,460 sq. mi.)

Frequency* of Yield	Associated River Discharge	T. Phosphorus as P		$NO_2 + NO_3$ as N		TKN as N		BOD_5	
	cfs	lbs/day/sq mi	lbs/day	lbs/day sq mi	lbs/day	lbs/day/sq mi	lbs/day	lbs/day/sq mi	lbs/day
5	34,600	1.68	19,250	24.22	277,560	8.60	98,560	27.6	316,300
50	6,470	0.38	4,350	1.73	19,830	1.47	16,850	7.8	89,390
95	1,200	0.08	920	0.11	1,260	0.43	4,930	1.7	19,490

* The percent of time of which a given frequency of yield in lbs/day/sq mi was equalled or exceeded

C. SUBURBAN AND URBAN RUNOFF

An analysis similar to that used for the Potomac at Great Falls was applied to data on Rock Creek and the Anacostia River. Based on these regression studies and flow duration curves, yield rates in terms of lbs/day/sq mi were determined as given in Table IV-5. These rates were used for the suburban areas in Virginia and Maryland.

For the District of Columbia, data on stormwater and urban runoff were obtained from a study of Washington overflows [6]. The rates and flow frequency percentages based upon the Rock Creek and the Anacostia River drainage areas were used.

The median loadings contributed from urban and suburban areas to the upper Potomac Estuary are tabulated below:

Parameter	Loadings (lbs/day)
BOD_5	12,500
TKN as N	2,560
$NO_2 + NO_3$	1,510
T. Phosphorus as P	850

The total loadings (lbs/day) of BOD and nutrients from suburban and urban runoff were fairly small when compared to those from the upper Potomac Basin. However, yield rates (lbs/day/sq mi) for the urban and suburban area, except for nitrites and nitrates, were significantly higher (Table IV-5). This indicates that as population in an area increases, the BOD, phosphorus, and TKN loadings from urban runoff will probably also increase.

Table IV-5
URBAN AND SUBURBAN RUNOFF CONTRIBUTIONS TO UPPER POTOMAC ESTUARY
(Great Falls to Indian Head)

	Area sq mi	Duration* Yield Rate	T. Phosphorus as P		$NO_2 + NO_3$ as N		TKN		BOD_5	
			lbs/day/sq mi	lbs/day	lbs/day/sq mi	lbs/day	lbs/day/sq mi	lbs/day	lbs/day/sq mi	lbs/day
Maryland	352	5%	3.30	1,200	15.65	5,500	30.40	10,700	64.0	22,500
	352	50%	1.00	350	1.71	600	3.20	1,100	9.6	3,400
	352	95%	0.10	35	0.20	70	0.60	210	1.2	420
Virginia	300	5%	3.30	1,000	15.65	4,700	30.40	9,100	64.0	19,200
	300	50%	1.00	300	1.71	510	3.20	960	9.6	2,900
	300	95%	0.10	30	0.20	60	0.60	180	1.2	360
District of Columbia	62	5%	17.74	1,100	27.42	1,700	41.90	2,600	62.9	3,900
	62	50%	3.23	200	6.45	400	8.10	500	10.0	6,200
	62	95%	0.40	25	0.40	50	1.50	90	4.8	300
Total	714	5%	4.62	3,300	16.66	11,900	31.37	22,400	63.86	45,600
	714	50%	1.20	850	2.11	1,510	3.58	2,560	17.50	12,500
	714	95%	0.12	90	0.25	180	0.67	480	1.51	1,080

* The percent of time of which a given duration of yield in lbs/day/sq mi was equaled or exceeded

D. SUMMARY AND COMPARISON OF NUTRIENTS, BOD, AND CARBON CONTRIBUTIONS

For the 50- and 95-percent flow durations, the largest source of BOD and nutrients is from wastewater discharges in the Washington area. As summarized below, under low-flow conditions, wastewater discharges contributed over 55 percent of all four parameters.

	95% Low-Flow Condition Potomac R. Flow = 1200 cfs		50% Median-Flow Condition Potomac R. Flow = 6470 cfs	
Parameter	Total From all Sources (lbs/day)	Percentage From Wastewater (%)	Total From all Sources (lbs/day)	Percentage From Wastewater (%)
T. Oxygen Demand	515,800	88	733,000	62
T. Carbon	380,000	55	720,000	29
T. Nitrogen	66,900	90	100,000	60
T. Phosphorus	25,000	96	29,300	82
BOD_5	161,580	87	242,900	58

Even under median-flow conditions, the contribution of total oxygen demand, total nitrogen, and total phosphorus is largest from the wastewater treatment facilities. At the 5-percent frequency or for a Potomac flow of 34,600 cfs, only in the case of phosphorus (52%) is the largest percentage from wastewater discharges (see Table IV-6).

Table IV-6
SUMMARY OF CONTRIBUTIONS OF NUTRIENTS, BOD, AND CARBON

Loading* Duration	Parameter	Upper Potomac River Basin		Urban and Suburban Runoff		Wastewater Treatment Facility Discharge		Total
		lbs/day	% of Total	lbs/day	% of Total	lbs/day	% of Total	lbs/day
5%	BOD_5	316,300	62.89	45,600	9.07	141,000	28.04	502,900
	Total Oxygen Demand	2,030,000	76.46	169,000	6.36	456,000	17.18	2,655,000
	Total Carbon	1,400,000	82.50	87,000	5.23	210,000	12.37	1,697,000
	Total Nitrogen	376,000	79.99	34,300	7.29	60,000	12.75	470,300
	Total Phosphorus	19,300	41.41	3,300	7.08	24,000	51.51	46,600
50%	BOD_5	89,400	36.81	12,500	5.15	141,000	58.04	242,900
	Total Oxygen Demand	247,000	33.70	30,000	4.09	456,000	62.21	733,000
	Total Carbon	480,000	66.67	30,000	4.17	210,000	29.16	720,000
	Total Nitrogen	36,000	35.97	4,070	4.07	60,000	59.96	100,070
	Total Phosphorus	4,400	15.04	850	2.91	24,000	82.05	29,250
95%	BOD_5	19,500	12.07	1,080	0.67	141,000	87.26	161,580
	Total Oxygen Demand	56,000	10.86	3,800	0.74	456,000	88.40	515,800
	Total Carbon	160,000	42.11	10,000	2.63	210,000	55.26	380,000
	Total Nitrogen	6,200	9.27	660	0.99	60,000	89.74	66,860
	Total Phosphorus	920	3.68	90	0.36	24,000	95.96	25,010

* The percent of time for which a given loading is equaled or exceeded. The 5%, 50%, and 95% corresponds to a freshwater flow into the estuary of 34,600 cfs, 6,470 cfs, and 1,200 cfs, respectively.

CHAPTER V

WATER QUALITY CONDITIONS AND TRENDS

The water quality problems resulting from discharge of municipal wastewater into the Potomac Estuary are not new. The first three conclusions of a study conducted in 1913 [7], which are as applicable today as they were then, are listed below:

1. "That at no point above Washington is the water of the Potomac River safe for use as a public water supply without reasonable treatment.

2. "That portions of the main or Georgetown Channel, between the Chain Bridge and the junction of the main channel with Anacostia River and Washington Channel, are so heavily polluted that the water is unsafe for bathing purposes. The water from this section supplies the Tidal Basin.

3. "That the conditions of that area in Anacostia River in the neighborhood of the sewage-pumping station and at the junction of the three channels is bad during hot weather, at times constituting a nuisance; but that, when the improvements now planned or under construction are completed, these conditions should no longer exist."

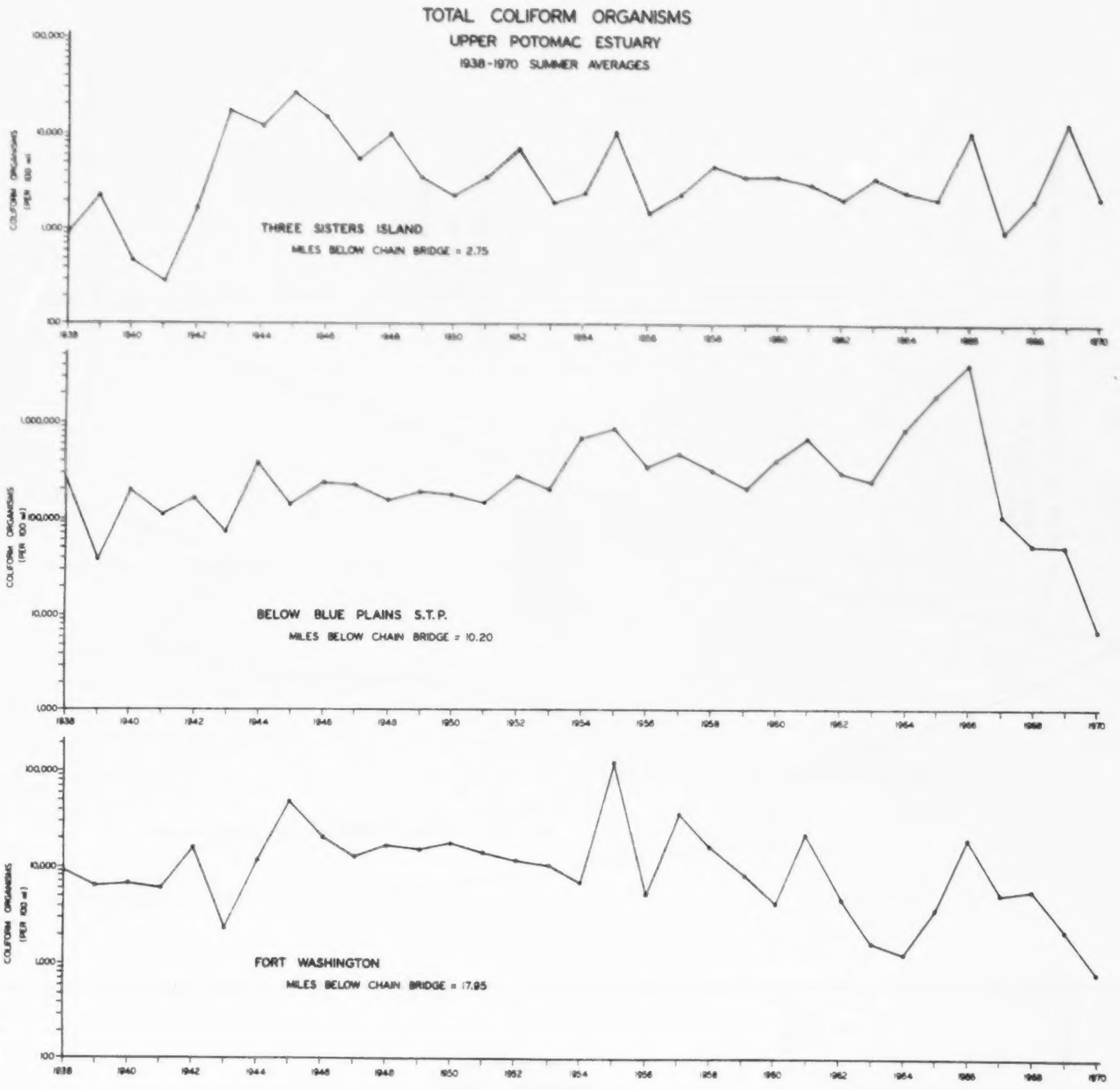
Not only has the water quality problem as stated above persisted, conditions have deteriorated considerably.

A. BACTERIAL DENSITIES

Bacterial densities in the Potomac Estuary have been determined routinely since 1938. Total coliform counts in the Potomac at Three Sisters Island have remained fairly constant for the past 20 years at about 2,000 MPN/100 ml during the summer months (Figure V-1). In contrast, total coliform densities in the estuary have increased to over 2,000,000 in 1966 and then decreased to less than 7,000 in 1970 near the Blue Plains Sewage Treatment Plant. The reduction in recent years can be attributed in part to an increase in overall wastewater treatment efficiency including chlorination, and to higher river flows.

During 1969, continuous year-around chlorination of final effluents was initiated at all major plants. This appears to be the most significant single factor in the reduction of bacterial densities in the estuary near Washington. As shown in Figure V-2, there has been a corresponding reduction in fecal coliform counts under similar flow and temperature conditions in August 1968 and August 1970.

The highest fecal coliform densities in 1968 were found between River Mile 10 and 15 in the vicinity of the major wastewater discharges. In August 1970, the highest densities were found at River Mile 7 in the vicinity of Hains Point. At times, 10 to 20 mgd of untreated sewage is discharged into the estuary as a result of inadequate sewerage and treatment plant capacity at Blue Plains. Urban runoff from the Anacostia River and Rock Creek basins also add to the fecal coliform problem.



TOTAL COLIFORM ORGANISMS
UPPER POTOMAC ESTUARY
1938-1970 SUMMER AVERAGES

FIGURE V-1

FECAL COLIFORM DENSITIES
UPPER POTOMAC ESTUARY

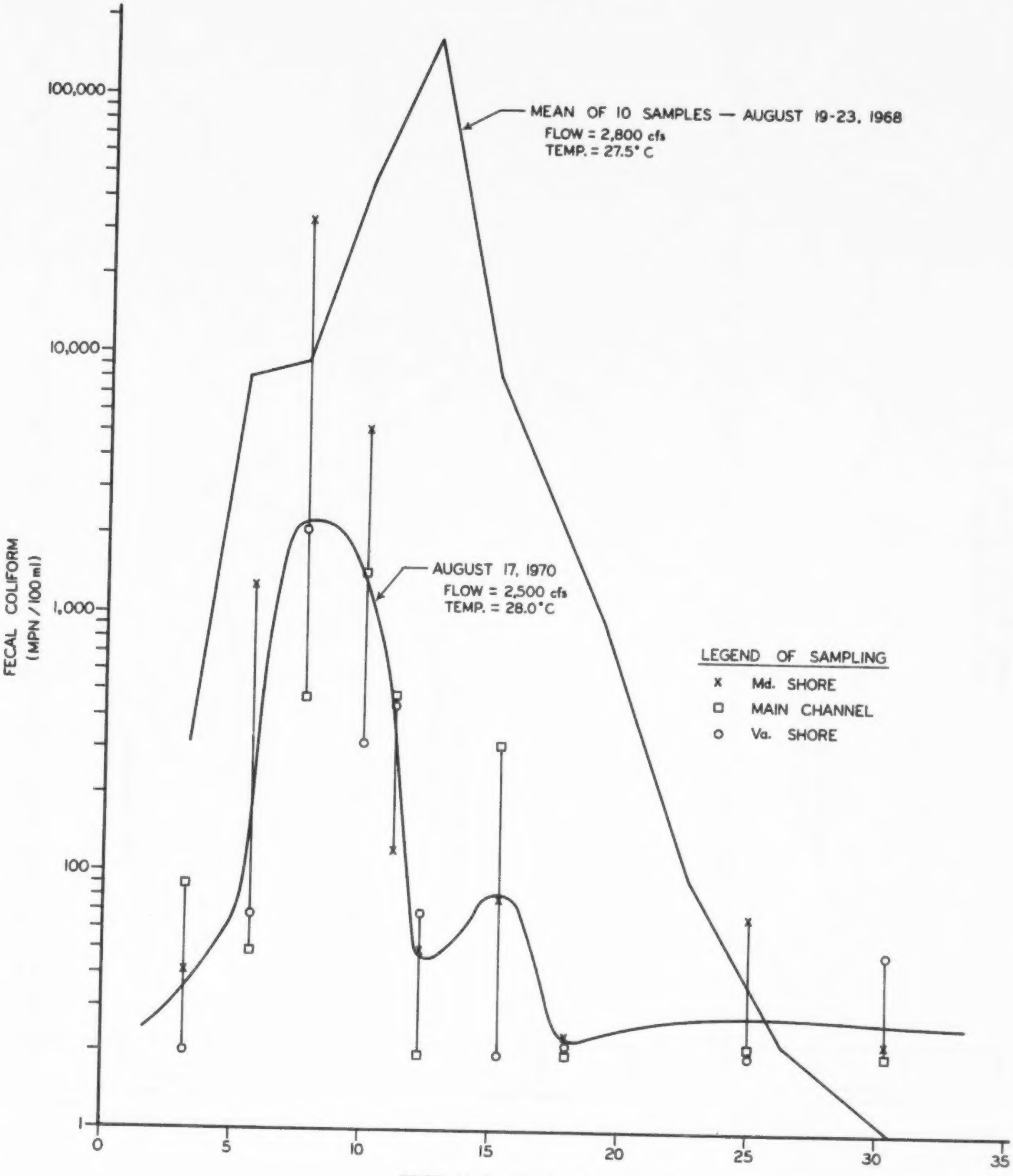


FIGURE V-2

At the Fort Washington monitoring station, total coliform densities during the summer months have remained fairly constant except for recent downtrends (see Figure V-1). These downtrends can also be attributed to recent chlorination of treatment plant effluents.

B. DISSOLVED OXYGEN

Dissolved oxygen (DO) concentrations in the upper Potomac Estuary have also been routinely monitored since 1938. As shown in Figure V-3, there has been a continuous downward trend in DO in the Potomac Estuary near and below the wastewater discharges.

A significant increase in DO occurred in the early 1960's near the Blue Plains outfall. However, with the population increase of the past decade and little or no increase in treatment plant capacities, DO in the Blue Plains vicinity during the summer months is now approaching the levels of the late 1950's.

With increased loadings to existing waste treatment plants and additional facilities being located farther downstream, the number of miles affected by wastewater effluents has increased. As presented in Figure V-3, the minimum 28-day DO concentrations at Fort Washington have decreased from approximately 5.0 mg/l to less than 4.0 mg/l since 1938. Currently, about 20 miles of the estuary has a DO concentration of less than 5.0 mg/l (the water quality standard for that reach of the Potomac) during low-flow periods.

The DO concentration at any given location in the estuary is a function of many factors including biological activity, freshwater inflow, temperature, wastewater loadings, and tidal stage. On four sampling cruises made during the summer months of 1969, the locations and readings of the minimum concentration of DO varied as shown in Figure V-4. Minimum dissolved oxygen readings of less than 2.0 mg/l were recorded on all four cruises, even when the freshwater inflow was as high as 8,890 cfs. Increases in freshwater inflows caused the point of minimum DO to move downstream as evidenced when the DO profiles for June 30 and August 14 are compared.

Data for the Potomac Estuary at the Woodrow Wilson Bridge (Figures V-5 and V-6) show the typical annual variation in DO. During the summer of 1965, DO concentrations ranged from 0.5 to 3.5 mg/l with an average of 2.0 mg/l. DO during the summer months of 1966 ranged from 0.5 to 3.0 mg/l with an average of 1.5 mg/l. For the months of September through December 1965, the DO concentrations remained depressed as a result of low-flow conditions. During December 1965, the DO was approximately 5.5 mg/l even when the water temperature was less than 10°C.

The DO concentration for a given time and location can also vary over the cross-section of the estuary. In the Piscataway embayment, DO varied from 4.0 to 12.0 mg/l during a sampling cruise made on June 27, 1970. At the same time, the main channel of the Potomac Estuary showed a fairly uniform DO (about 4.0 mg/l) as a result of tidal mixing (see Figure V-7). The higher DO concentrations in the embayment were attributed to the photosynthetic production by dense algal growths. During hours of darkness, the DO dropped to less than 8.0 mg/l in the embayment while it remained around 4.0 mg/l in the main Potomac.

DISSOLVED OXYGEN CONCENTRATION
UPPER POTOMAC ESTUARY
1938 - 1970

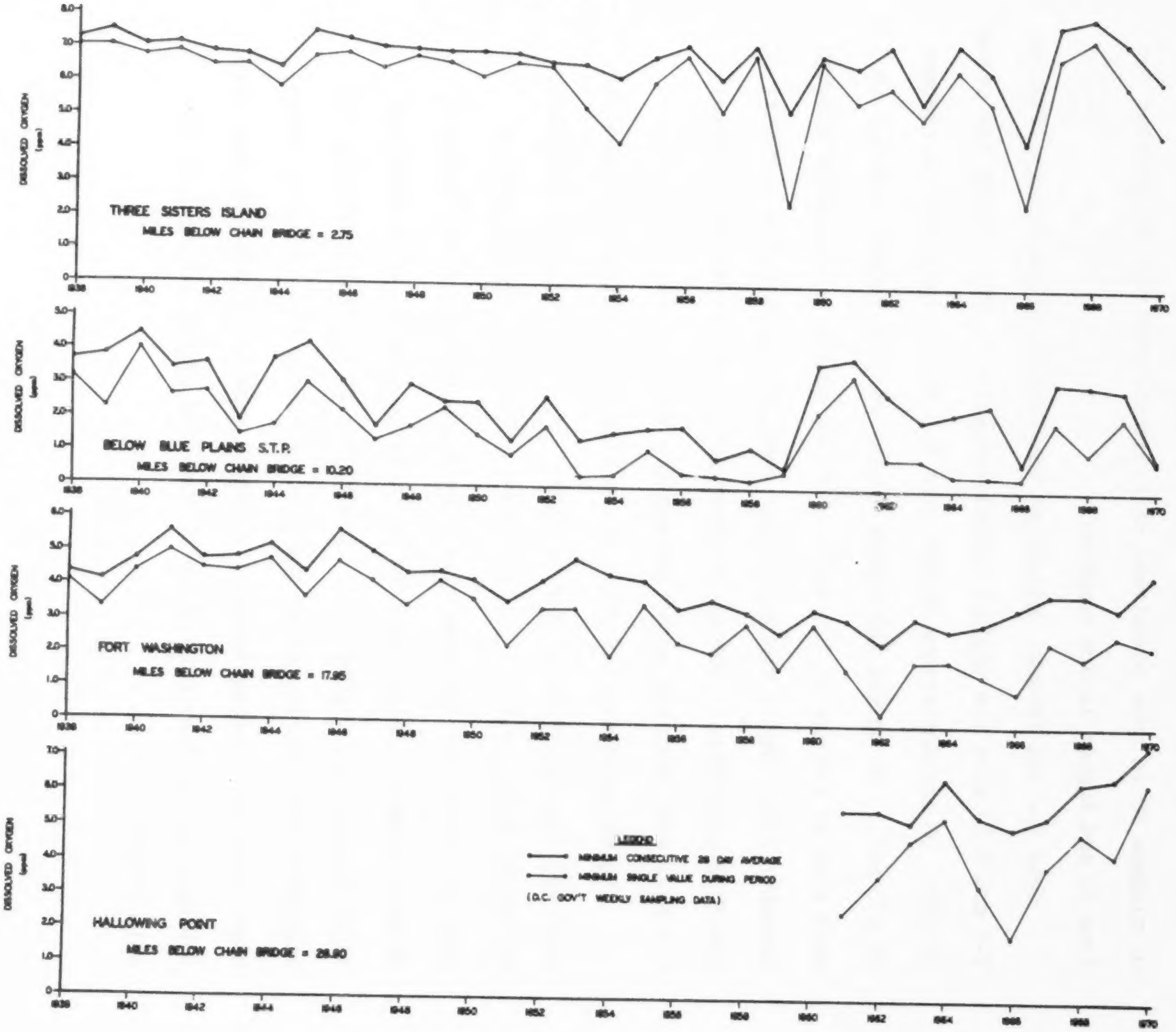


FIGURE V-3

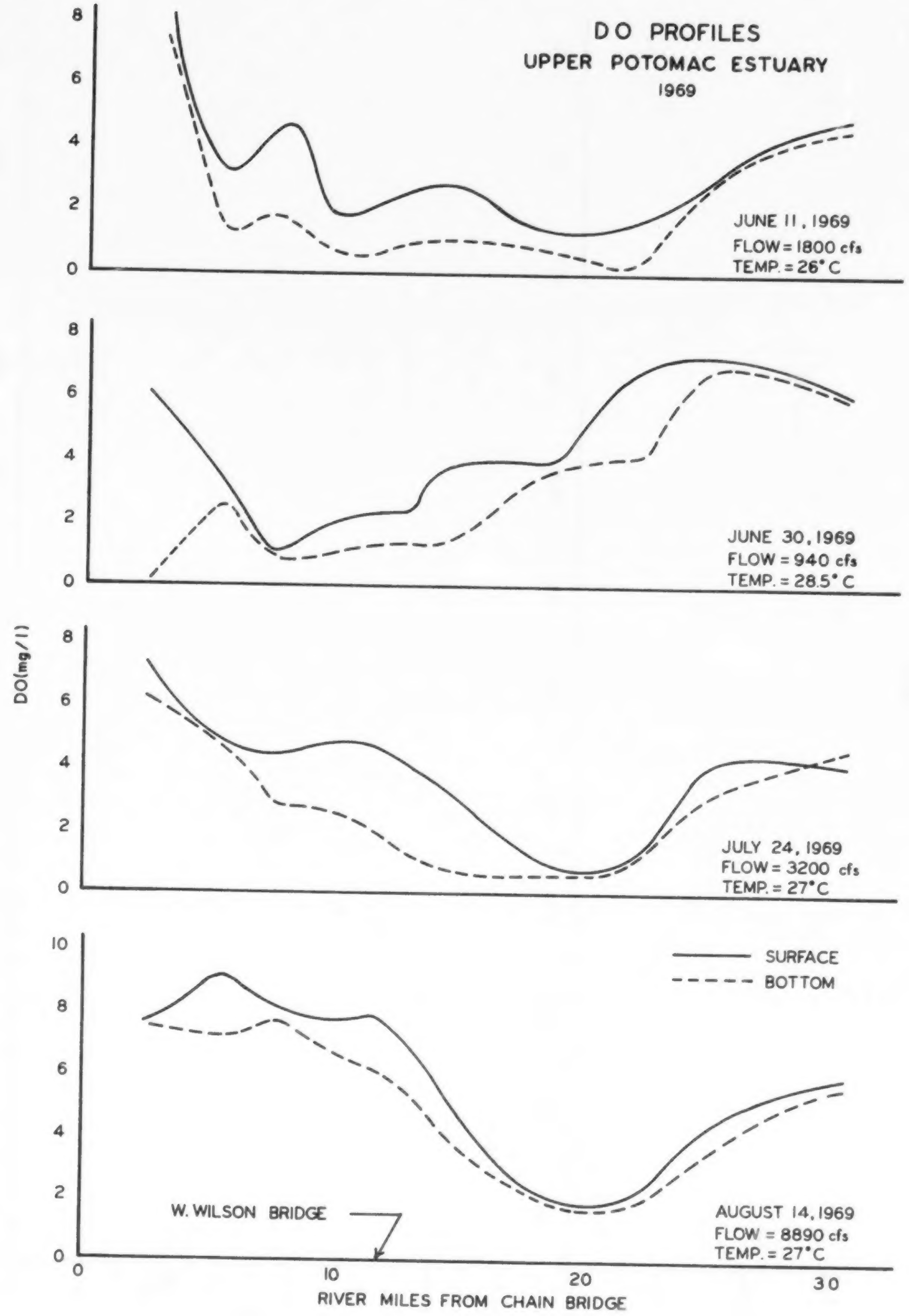
D O PROFILES
UPPER POTOMAC ESTUARY
1969
JUNE 11, 1969
FLOW = 1800 cfs
TEMP. = 26° C
JUNE 30, 1969
FLOW = 940 cfs
TEMP. = 28.5° C
JULY 24, 1969
FLOW = 3200 cfs
TEMP. = 27° C
AUGUST 14, 1969
FLOW = 8890 cfs
TEMP. = 27° C
SURFACE
BOTTOM
W. WILSON BRIDGE
DO(mg/l)
0
2
4
6
8
10
0
10
20
30
RIVER MILES FROM CHAIN BRIDGE

FIGURE V-4

DISSOLVED OXYGEN CONCENTRATION
POTOMAC ESTUARY at WOODROW WILSON BRIDGE
1965

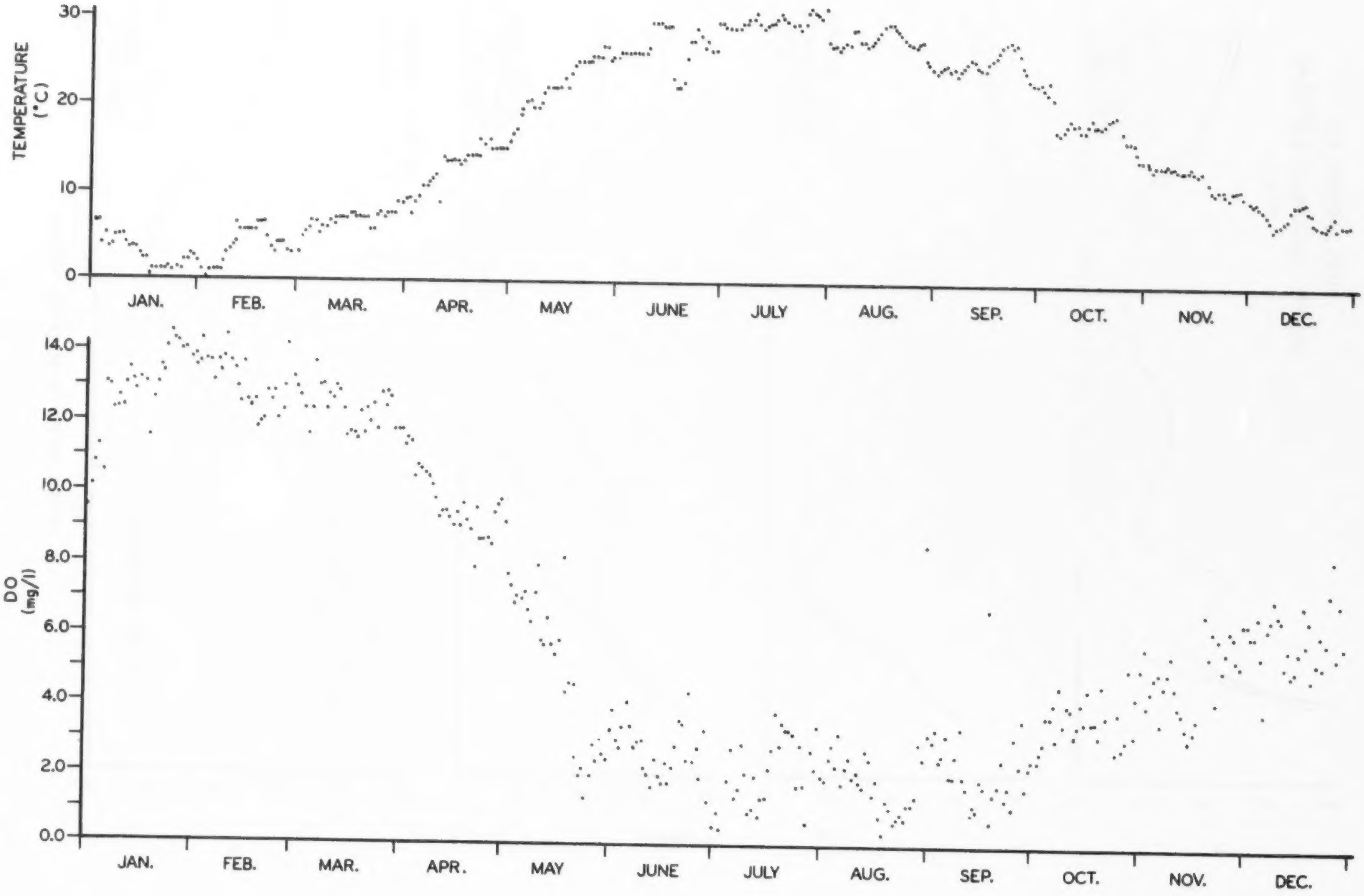


FIGURE V-5

DISSOLVED OXYGEN CONCENTRATION
POTOMAC ESTUARY at WOODROW WILSON BRIDGE
1966

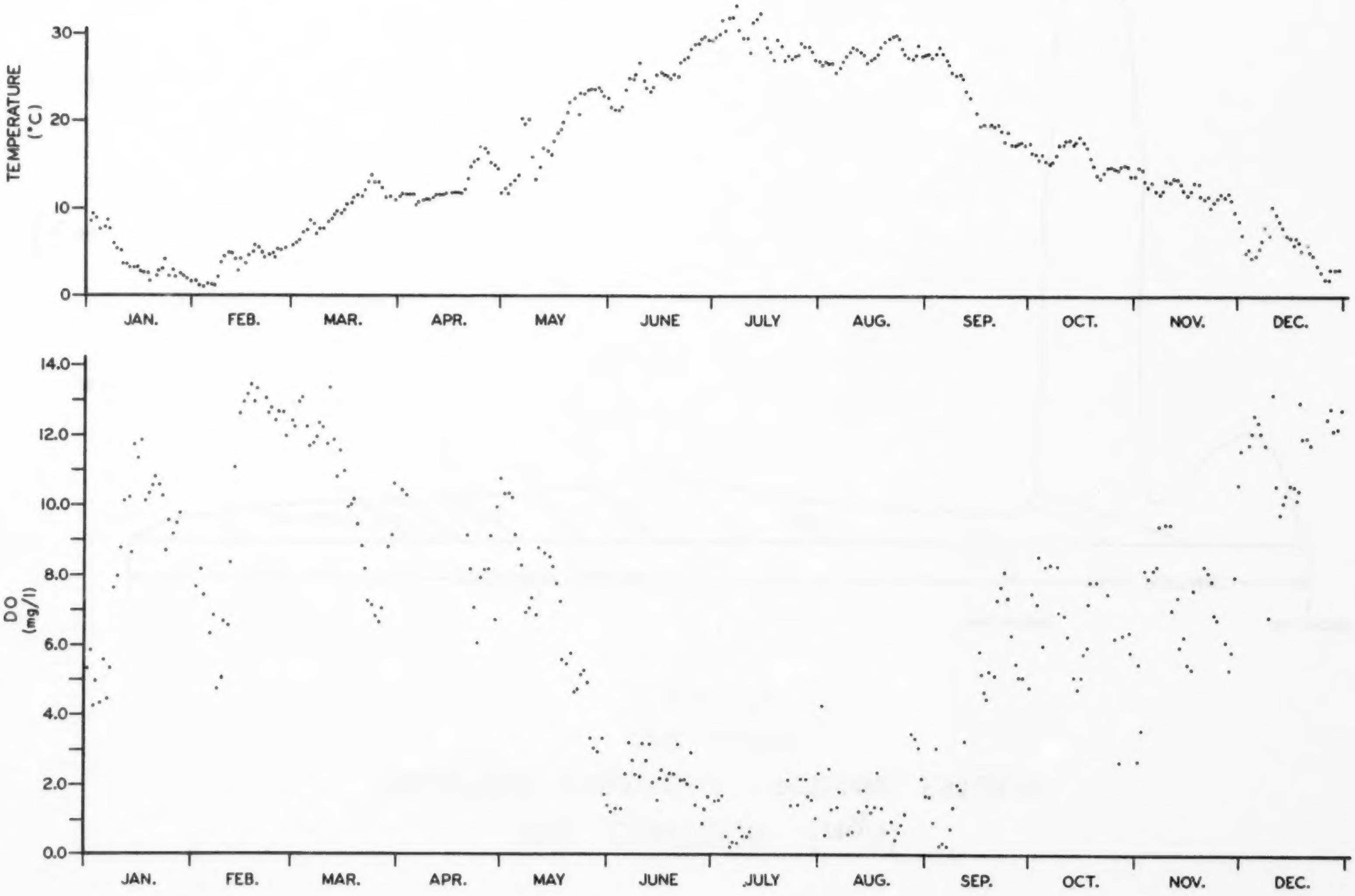


FIGURE V-6

DO CONTOUR (mg/l)

PISCATAWAY EMBAYMENT – POTOMAC ESTUARY

JUNE 22, 1970

12:00 A.M.

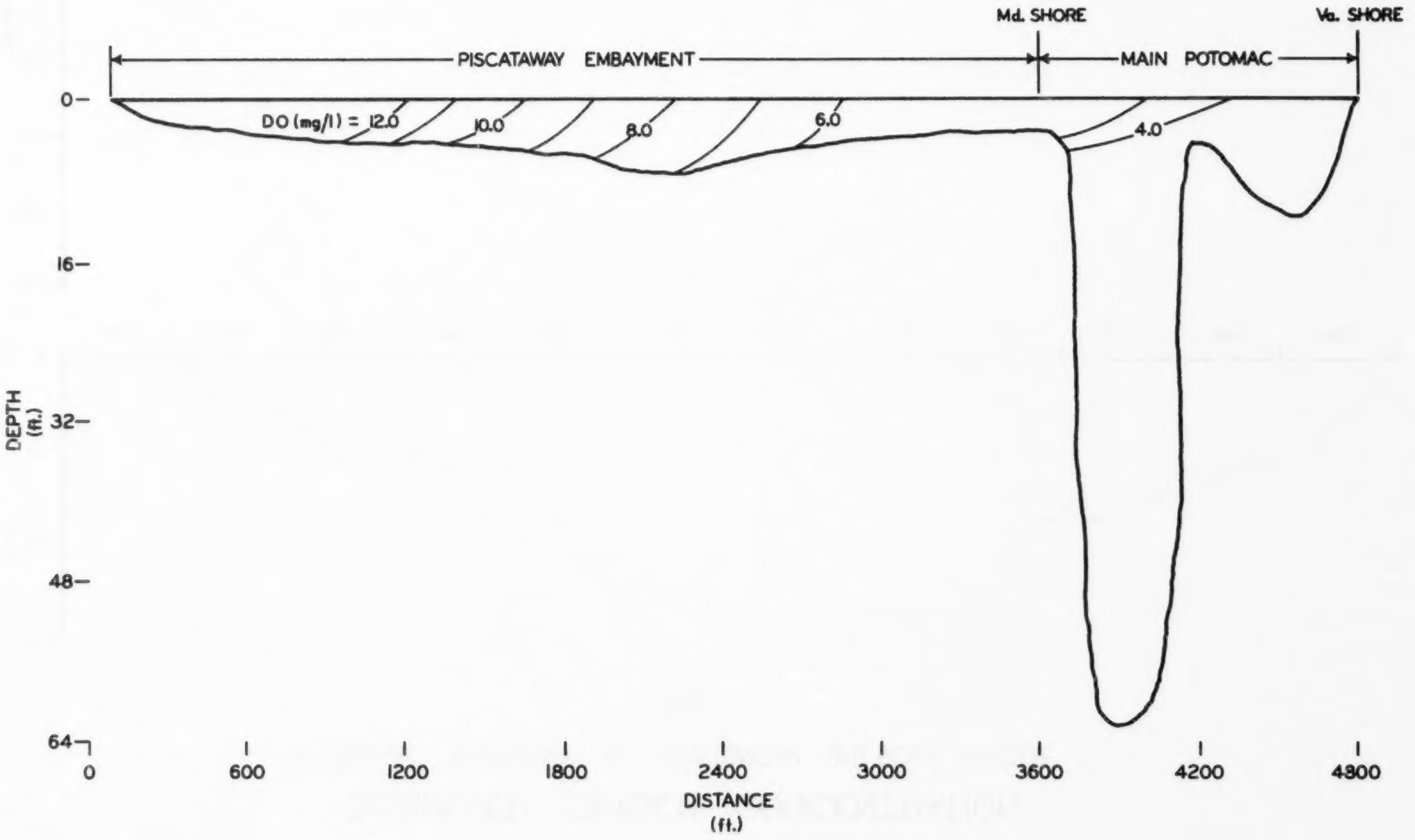


FIGURE V-7

C. SILT AND DEBRIS

The upper Potomac Estuary has changed drastically during the past hundred years. At one time, water covered what is now the corner of Seventeenth Street and Constitution Avenue. Potomac Park and Hains Point did not exist. Tidewaters covered the present site of National Airport and Bolling Field. The Anacostia River was a broad stream with extensive mud flats. Many of the tidal flats of the upper Potomac were formed by sediments and have been transformed by dredged material into the present Washington area waterfronts.

The silt in the Potomac Estuary can be attributed to three sources:

a. Above Great Falls, mainly forested;

b. Washington metropolitan area, mainly urban;

c. Coastal area, mainly rural.

For the water years 1961 through 1968, the average sediment yield of the upper Potomac above Great Falls was 1.98 billion lbs/year (Table V-1). The highest percentage of the annual contribution occurred during either February or March with the maximum month values ranging from 51 percent to 90 percent of the total annual load.

The Northwest Branch of the Anacostia River near Colesville, Maryland with a drainage area of 21.1 square miles showed an annual yield ranging from 1.0 to 1.6 million lbs/sq mile with an average of 1.34 million lbs/sq mi/yr (Table V-2). This is about seven times greater than that from the upper basin which averages about 0.190 million lbs/sq mi/yr.

Table V-1

SEDIMENT DATA

Potomac River Basin Below Confluence of Monocacy River

Year	Total for Year (1000 lbs)	Maximum Month	% of Annual for Maximum Month	Annual Yield (1000 lbs/sq mi)
1961	2,516,600	February	65.7	240
1962	1,997,600	March	64.2	190
1963	2,379,000	March	89.8	227
1964	2,052,000	March	51.6	196
1965	1,504,000	March	54.3	143
1966	1,175,000	February	50.8	112
1967	2,562,000	March	84.0	244
1968	1,684,000			159
Average	1,984,000			190

* Sediment data based on a summation of Potomac River at Point of Rocks and Monocacy River at Jug Bridge. Total drainage above the sampling station is equal to 10,468 square miles.

Table V-2

SEDIMENT DATA

Northwest Branch Anacostia River near Colesville, Maryland
(Drainage Area = 21.1 sq mi)

Year	Total for Year (1000 lbs)	Annual Yield (1000 lbs/sq mile)
1963	33,600	1,590
1964	23,200	1,090
1965	32,800	1,540
1966	28,800	1,360
1967	30,000	1,420
1968	21,100	1,000
Average	28,300	1,341

Applying the Anacostia station average (1.34 million lbs/sq mi/yr) to the entire Washington metropolitan area and a yield rate of 0.20 million lbs/sq mile to the lower coastal area, an estimate of the silt loading to the entire Potomac River is as follows:

Area	Yield (1000 lbs/sq mi/yr)	Drainage Area (sq mi)	Average Annual Loading (1000 lbs/yr)
Upper Potomac (above Great Falls)	190	11,640	2,200,000
Washington Area	1,340	714	957,000
Lower Coastal Area	200	2,326	465,000
Total	246*	14,670	3,622,000

*Average Annual Yield

The upper basin is the greatest source of sediments.

In addition to the obvious silting of navigation channels, sediments have other relationships to water quality management problems, some which are favorable and some unfavorable. During periods of high flow and suspended sediment load, the Potomac contains correspondingly greater quantities of organic carbon, nitrogen and phosphorus. The suspended and adsorbed pollutants are deposited as the silt settles, primarily in the upper 20 miles of the Potomac Estuary. During high runoff periods, the upper 10 to 20 miles is chocolate brown in color and aesthetically objectionable. Since the high silt loadings usually occur during the spring months when fish are spawning in the estuary, the silt may cover freshly laid eggs, thus reducing the effective spawning area in the upper estuary.

While silt transports a considerable amount of adsorbed nutrients during high-river flows, the overall effect is to reduce the nutrient concentration in the estuary, especially phosphorus. Sampling before and after a period of extremely high runoff in March 1967, as reported by CTSL [8], confirmed this observation. Silt also tends to cover much of the organic matter deposited from wastewater discharges. This covering generally reduces the availability of nutrients and oxygen demanding material from bottom deposits.

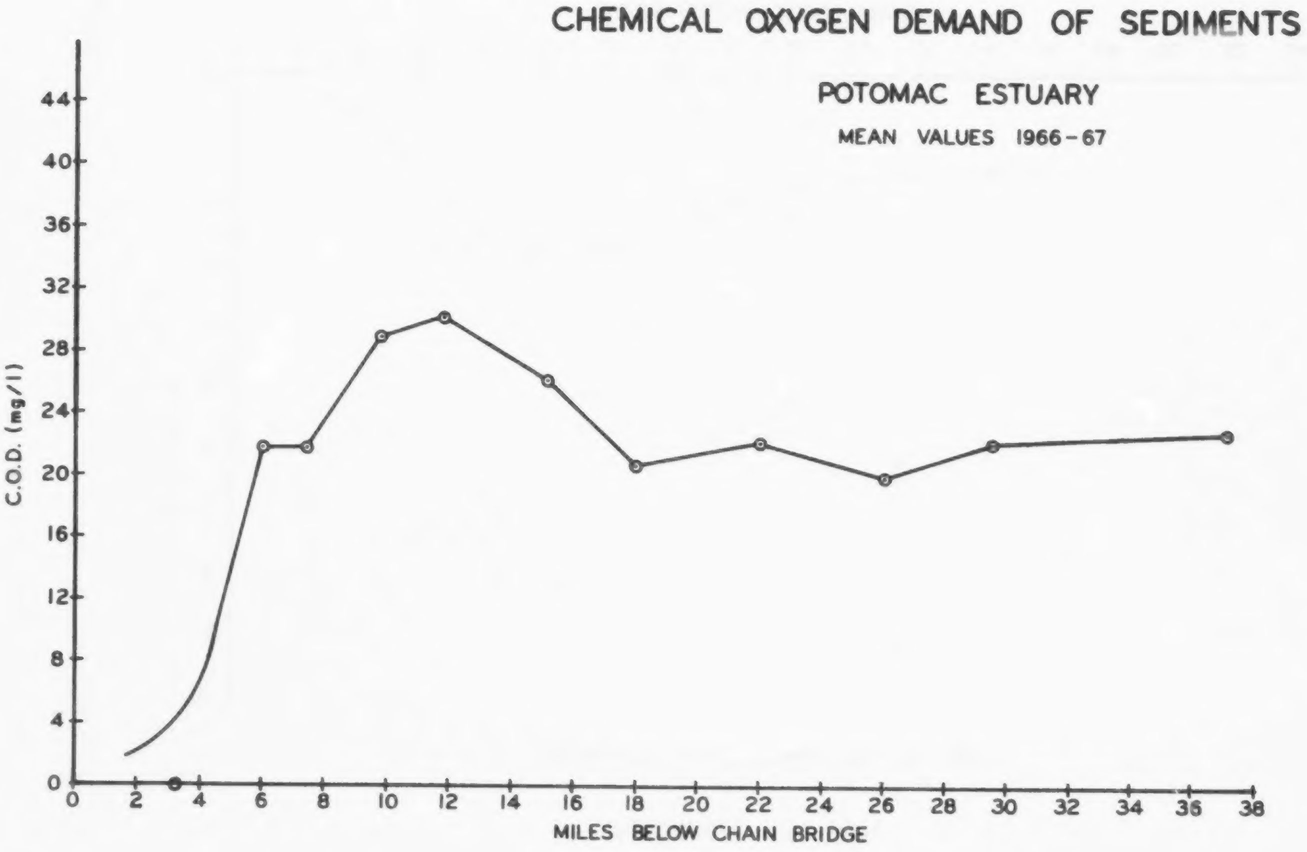
It was observed by CTSL on numerous occasions that suspended sediments contribute to algal control in the upper estuary. During the summer months, runoff resulting from heavy rainfall usually causes high turbidity in the upper estuary which restricts light penetration in the water and reduces algal growth even though all other environmental conditions may be favorable.

During the low-flow periods of 1966 and 1970, a reduction in turbidity in the upper estuary along with other favorable environmental condtions caused a significant increase in nuisance algal blooms near and above Woodrow Wilson Bridge [52]. These nuisance blooms can be expected to become more frequent as the silt control program becomes more effective unless there is a simultaneous adequate removal of nutrients from wastewater effluents.

During periods of high runoff, large quantities of debris enter the estuary from the upper basin as well as from the metropolitan area.

Debris from the upper basin is typically trees, brush, leaves, and miscellaneous trash, and is usually partially decomposed. Debris from the metropolitan area not only enters the estuary from local streams but also from storm sewers and often contains paper, vegetable and fruit peelings, styrofoam cups, etc. It appears that better solid-waste management practices would decrease the amount of local debris entering the estuary.

The effect of the increased silt and debris organic loadings on the oxygen resources of the estuary has not been well defined. Based upon DO studies made during a period of heavy precipitation, it appeared that increased flows and the resulting dilution minimized any immediate effect on the oxygen budget. Most of the organic matter carried into the estuary by silt and debris settles and contributes to the benthic oxygen demand. CTSL studies in the Potomac Estuary indicated that oxygen uptake from benthic deposits was about twice as large in areas with treated waste sludge deposits than in other areas of the upper estuary (Figure V-8). Analysis of sediments for chemical oxygen demand (COD), as presented in Figure V-9, shows a fairly close relationship between COD and benthic demand. From COD and uptake data, it appears that the effect of sludge deposits and other suspended solids from wastewater on the oxygen resources is much greater than the effect from the organic solids in silt and debris.



CHEMICAL OXYGEN DEMAND OF SEDIMENTS

POTOMAC ESTUARY

MEAN VALUES 1966-67

FIGURE V-9

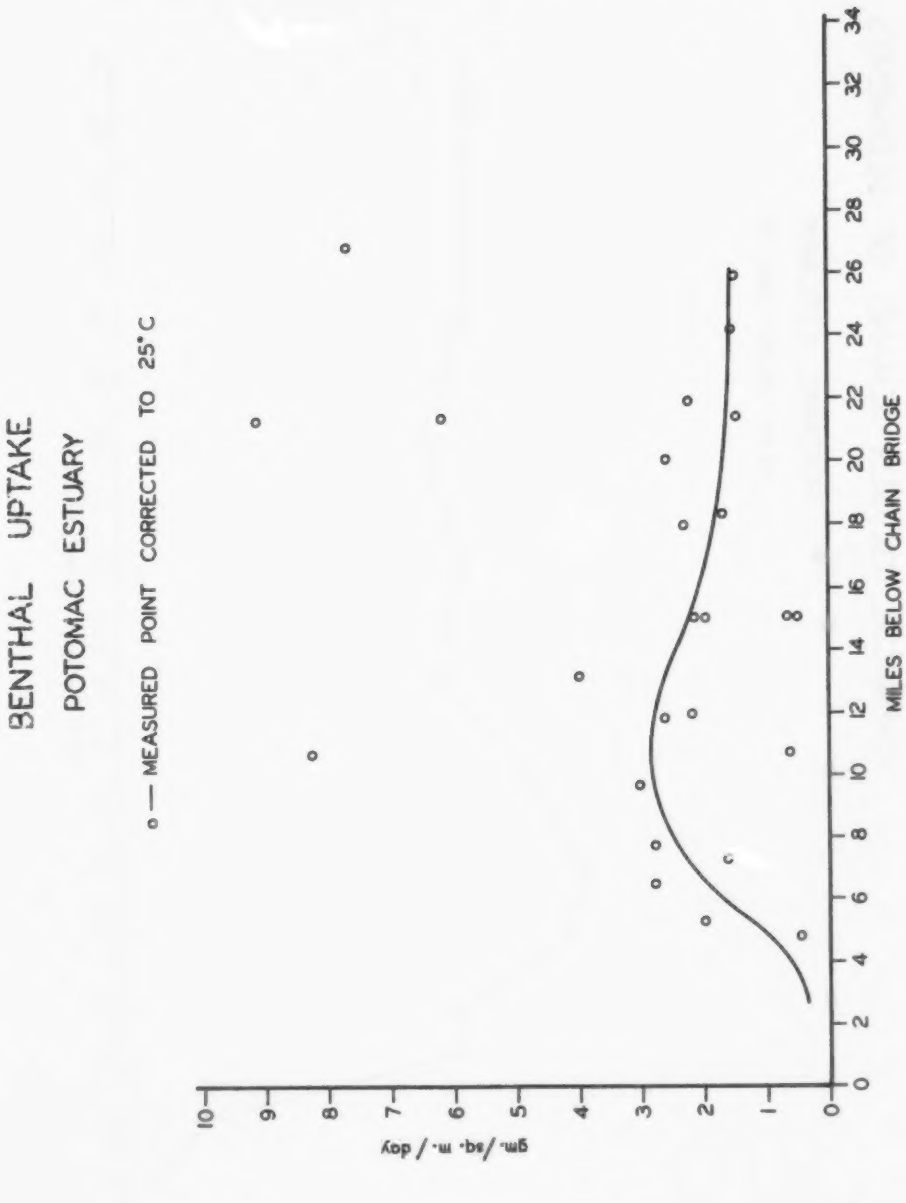

BENTHAL UPTAKE
POTOMAC ESTUARY
o — MEASURED POINT CORRECTED TO 25° C
gm./sq. m./day
0
1
2
3
4
5
6
7
8
9
10
MILES BELOW CHAIN BRIDGE
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
32
34

FIGURE V-8

D. NUTRIENTS AND ALGAL GROWTH

As discussed previously in this report, the major source of nitrogen and phosphorus in the upper Potomac Estuary is from the wastewater discharges in the Washington area. Total phosphorus has increased about 22-fold, from 1,100 lbs/day in 1913 to 24,000 lbs/day in 1970, with total nitrogen loadings increasing from 6,400 to 60,000 lbs/day. A greater increase for phosphorus reflects not only an increase in population but also the increased use of detergents. The current carbon loadings are about 100,000 lbs/day, approximately the same as they were in the mid-1940's. The decrease in organic carbon in the early 1960's was a result of the completion of present treatment facilities at Blue Plains.

1. Nutrient Concentrations in the Potomac Estuary

The concentrations and forms of phosphorus and nitrogen in the Potomac Estuary are a function of wastewater loadings, temperature, freshwater inflow, and biological activity. As shown in Figure V-10, the inorganic phosphorus varied considerably for the six stations sampled from March 1969 through September 1970. The concentration at Hains Point, located at the upper end of the tidal excursion of the major wastewater discharges, was fairly uniform averaging about 0.3 mg/l. At Woodrow Wilson Bridge, located below the Blue Plains wastewater discharge, the inorganic phosphorus increased appreciably with concentrations over 2.5 mg/l during periods of low flow such as those that occurred in July to October 1969 and September 1970. The

INORGANIC PHOSPHATE CONCENTRATION as PO_4

POTOMAC ESTUARY

1969 - 1970

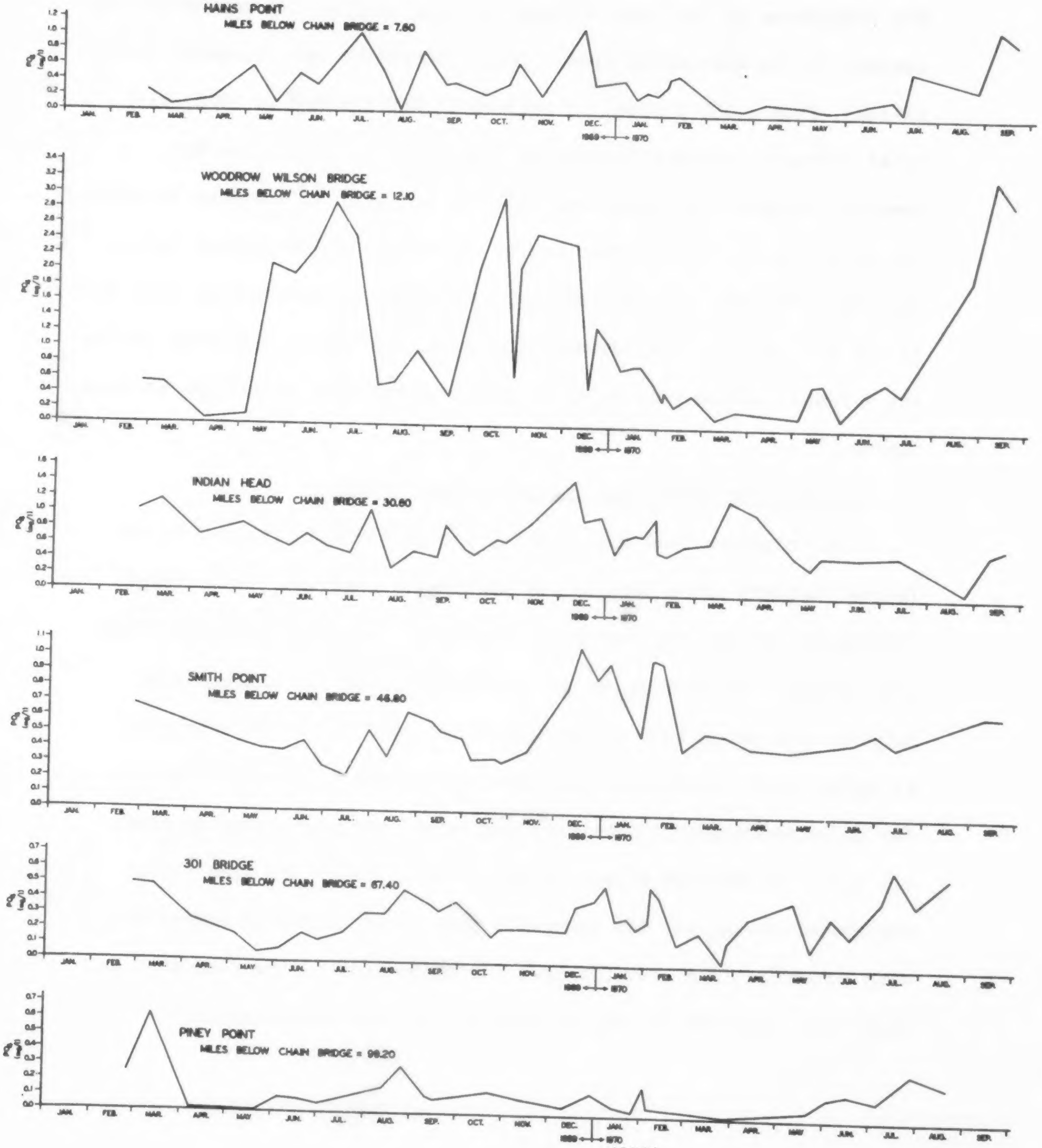


FIGURE V-10

remaining four downstream stations had concentrations progressively smaller.

It was observed that much of the phosphorus is deposited into the upper estuary even during high flows such as those in August 1969 and April 1970. During periods of high freshwater inflow, the sediment appears to adsorb more phosphorus than it releases. This is discussed in greater detail later.

The total phosphorus concentration closely parallels that of inorganic phosphorus. In the upper reach, the ratio of total phosphorus to inorganic phosphorus ranges from 1.1 to 1.5. The ratio is higher in the middle reach normally varying from 1.5 to 2.0 with the lower reach having a range from approximately 2.0 to 2.5.

The concentration of nitrite (NO_2) and nitrate (NO_3) nitrogen at Hains Point and Woodrow Wilson Bridge varies almost inversely to that of phosphorus (Figure V-11). The $NO_2 + NO_3$ concentration was highest in July and August 1969 and during the spring months of 1970. During these months, both high-flow periods, the phosphorus was lowest (Figure V-10). The increase of $NO_2 + NO_3$ at Indian Head as compared to Woodrow Wilson Bridge in May-June 1969, September-November 1969, and July 1970 was a result of the conversion of ammonia from the wastewater treatment plant discharges to NO_3. The extremely low concentration of $NO_2 + NO_3$ in the summer months at Smith Point was caused by uptake by algal cells [52]. During winter months algal utilization is lower [52], thus the concentrations of nitrates are high, as in January and April 1970. At Piney Point, concentrations of $NO_2 + NO_3$ are usually less than 0.1 mg/l.

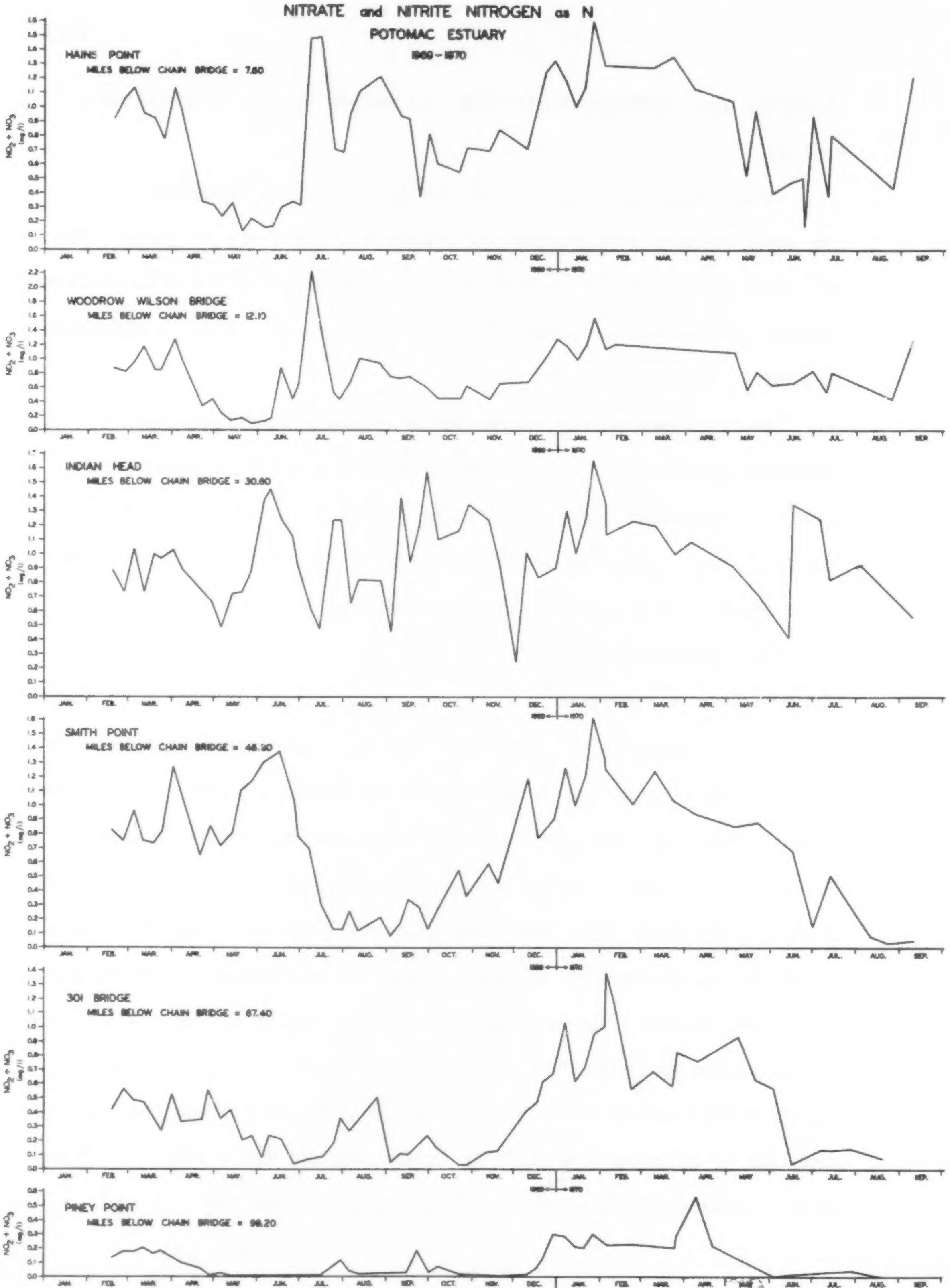

NITRATE and NITRITE NITROGEN as N
POTOMAC ESTUARY
1969-1970
HAINS POINT
MILES BELOW CHAIN BRIDGE = 7.60
WOODROW WILSON BRIDGE
MILES BELOW CHAIN BRIDGE = 12.10
INDIAN HEAD
MILES BELOW CHAIN BRIDGE = 30.60
SMITH POINT
MILES BELOW CHAIN BRIDGE = 46.90
301 BRIDGE
MILES BELOW CHAIN BRIDGE = 67.40
PINEY POINT
MILES BELOW CHAIN BRIDGE = 98.20
$NO_2 + NO_3$ (mg/l)
JAN. FEB. MAR. APR. MAY JUN. JUL. AUG. SEP. OCT. NOV. DEC. JAN. FEB. MAR. APR. MAY JUN. JUL. AUG. SEP.
1969 ← → 1970

FIGURE V-11

As shown in Figure V-12, the concentration of ammonia nitrogen is also affected by flow and temperature conditions. Although large quantities of ammonia are discharged from wastewater treatment facilities into the Potomac near Woodrow Wilson Bridge, the ammonia at Indian Head during the summer months is low because of nitrification.

During the summer and early fall months, the average ranges of pH, alkalinity, and free dissolved CO_2 (measured by titration) for the five stations in the upper and middle reaches were:

Location	pH (units)	Alkalinity (mg/1 as $CaCO_3$	Free Dissolved CO_2 (mg/1)
Chain Bridge	7.5 - 8.0	80 - 100	2 - 4
W. Wilson Bridge	7.0 - 7.5	90 - 110	8 - 12
Indian Head	7.2 - 8.0	70 - 90	6 - 10
Maryland Point	7.5 - 8.2	60 - 85	2 - 8
Rte. 301 Bridge	7.5 - 8.0	65 - 85	7 - 8

In the vicinity of the Woodrow Wilson Bridge, there is an increase in both alkalinity and CO_2 with a corresponding decrease in pH attributed to wastewater discharges. There is a decrease in both alkalinity and CO_2 with a corresponding increase in pH at the Indian Head and Maryland Point stations which are due to algal growths. In the lower estuary, the alkalinity and CO_2 increases while pH decreases. The algal standing crops are considerably smaller in this reach.

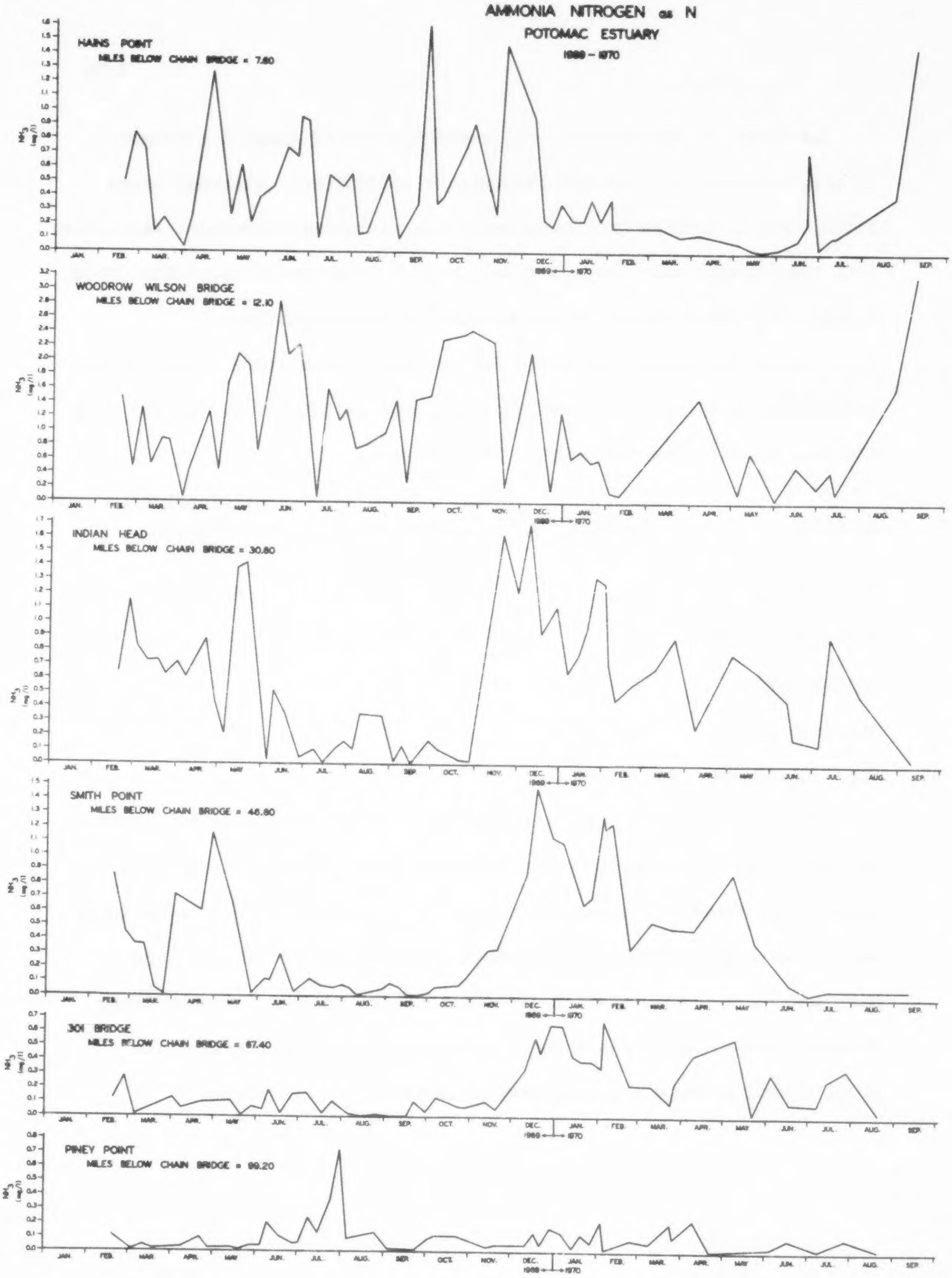

AMMONIA NITROGEN as N
POTOMAC ESTUARY
1969 - 1970
HAINS POINT
MILES BELOW CHAIN BRIDGE = 7.60
WOODROW WILSON BRIDGE
MILES BELOW CHAIN BRIDGE = 12.10
INDIAN HEAD
MILES BELOW CHAIN BRIDGE = 30.60
SMITH POINT
MILES BELOW CHAIN BRIDGE = 46.60
301 BRIDGE
MILES BELOW CHAIN BRIDGE = 67.40
PINEY POINT
MILES BELOW CHAIN BRIDGE = 99.20
NH_3 (mg/l)
JAN. FEB. MAR. APR. MAY JUN. JUL. AUG. SEP. OCT. NOV. DEC. JAN. FEB. MAR. APR. MAY JUN. JUL. AUG. SEP.
1969 ← → 1970

FIGURE V-12

2. Mathematical Models for Nutrient Transport

Mathematical models for predicting the movement and transport of phosphorus and nitrogen have been developed by CTSL. A detailed report of the modeling of nutrient transport is in preparation. Some of the model's predictions for phosphorus are shown in Figures V-13 and V-14 and for nitrogen in Figures V-15 and V-16.

The effects of temperature on nutrient transport, deposition, and utilization by the biota were determined by CTSL. The rates of phosphorus loss, ammonia utilization, and nitrate algal uptake as a function of temperature are shown in Figures V-17, V-18, and V-19, respectively.

These models, which considered the effects of temperature on the algal productivity rates, were used to investigate the role of nutrients in eutrophication. The models were also used to establish maximum allowable nutrient loadings by zones as presented later in this report.

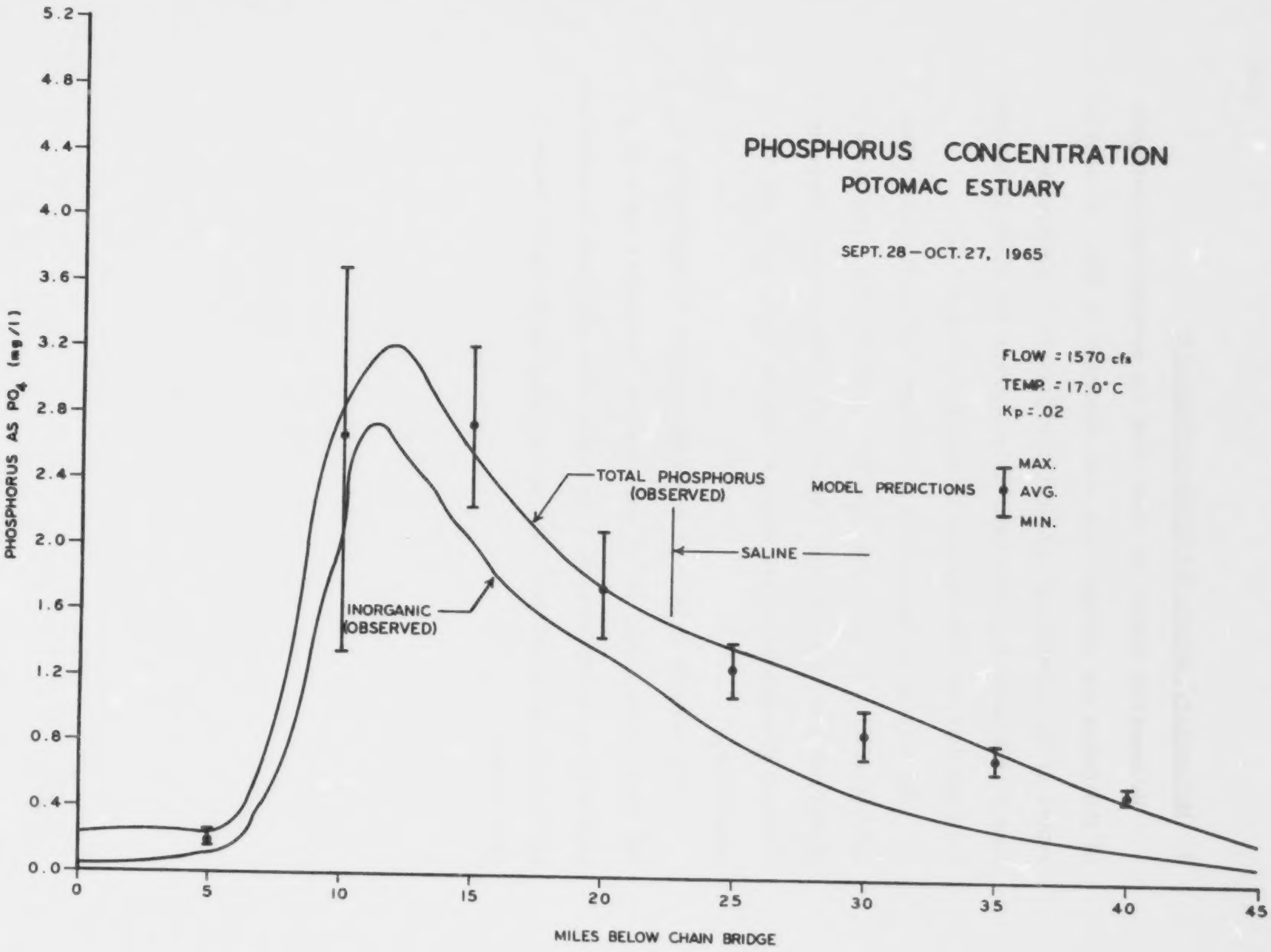

PHOSPHORUS CONCENTRATION
POTOMAC ESTUARY
SEPT. 28 – OCT. 27, 1965
FLOW = 1570 cfs
TEMP. = 17.0°C
Kp = .02
MODEL PREDICTIONS
MAX.
AVG.
MIN.
TOTAL PHOSPHORUS (OBSERVED)
INORGANIC (OBSERVED)
SALINE
PHOSPHORUS AS PO4 (mg/l)
0.0
0.4
0.8
1.2
1.6
2.0
2.4
2.8
3.2
3.6
4.0
4.4
4.8
5.2
0
5
10
15
20
25
30
35
40
45
MILES BELOW CHAIN BRIDGE

FIGURE V-13

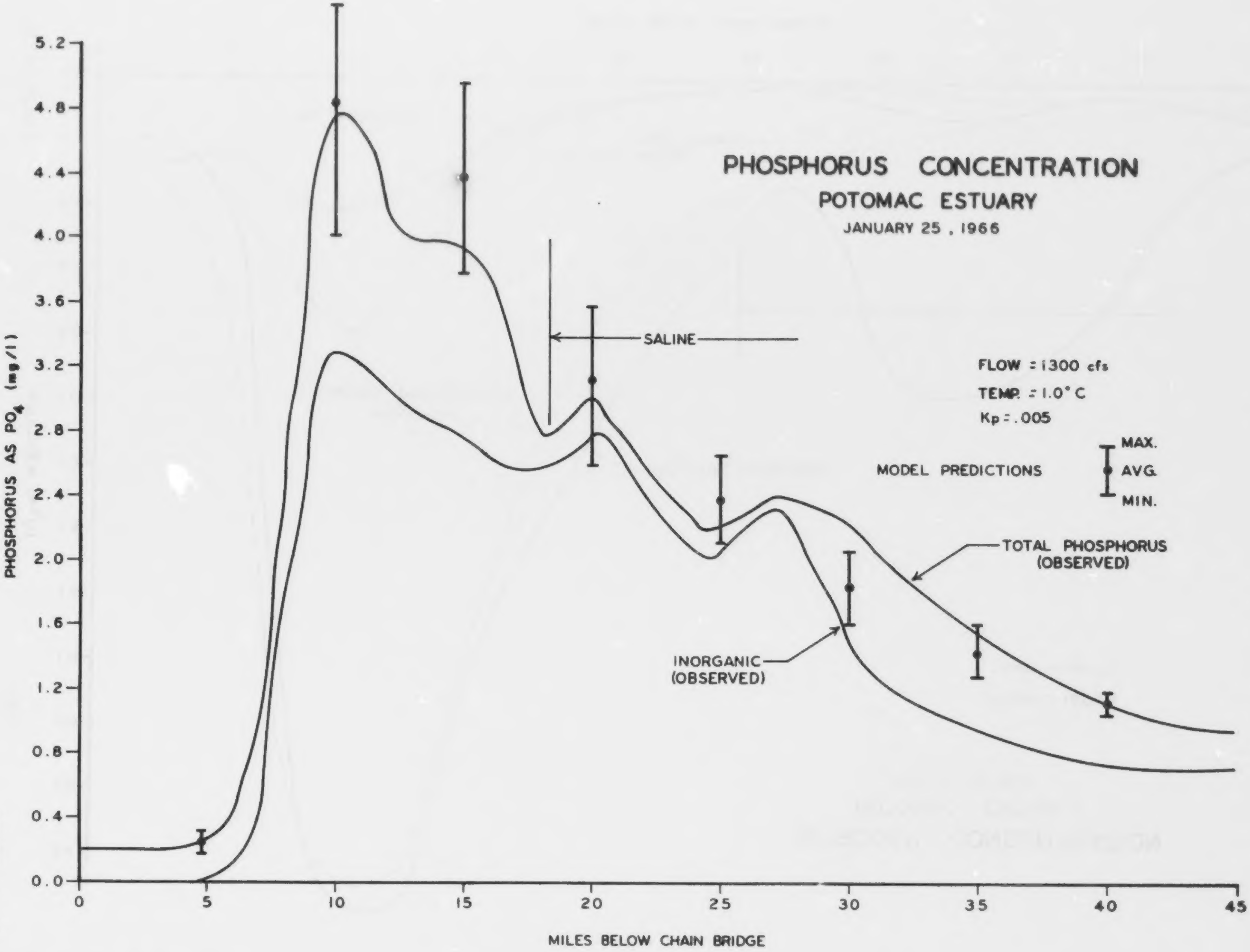

PHOSPHORUS CONCENTRATION
POTOMAC ESTUARY
JANUARY 25 , 1966
FLOW = 1300 cfs
TEMP. = 1.0° C
Kp = .005
MODEL PREDICTIONS
MAX.
AVG.
MIN.
SALINE
TOTAL PHOSPHORUS (OBSERVED)
INORGANIC (OBSERVED)
PHOSPHORUS AS PO4 (mg/l)
0.0
0.4
0.8
1.2
1.6
2.0
2.4
2.8
3.2
3.6
4.0
4.4
4.8
5.2
0
5
10
15
20
25
30
35
40
45
MILES BELOW CHAIN BRIDGE

FIGURE V-14

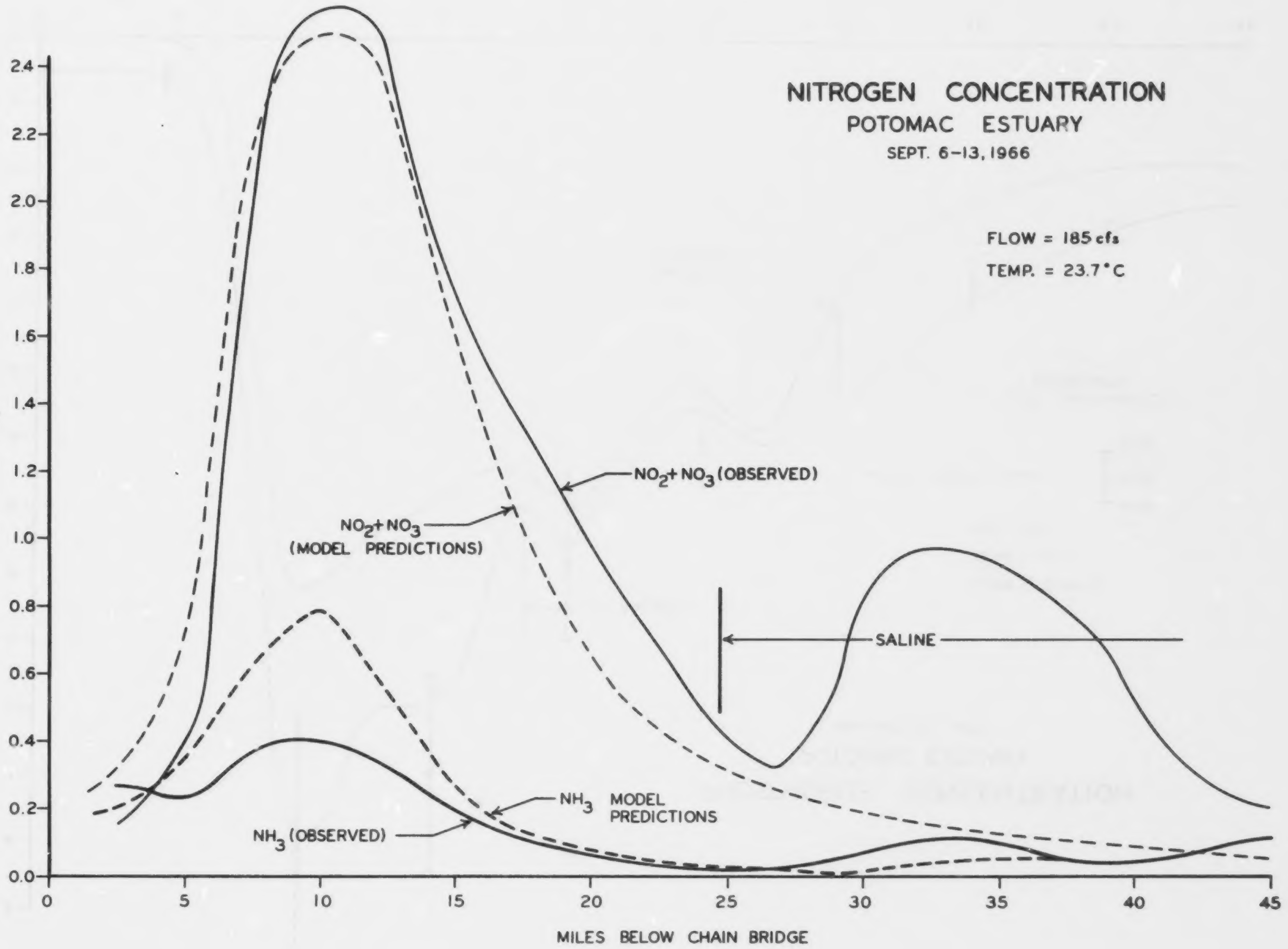
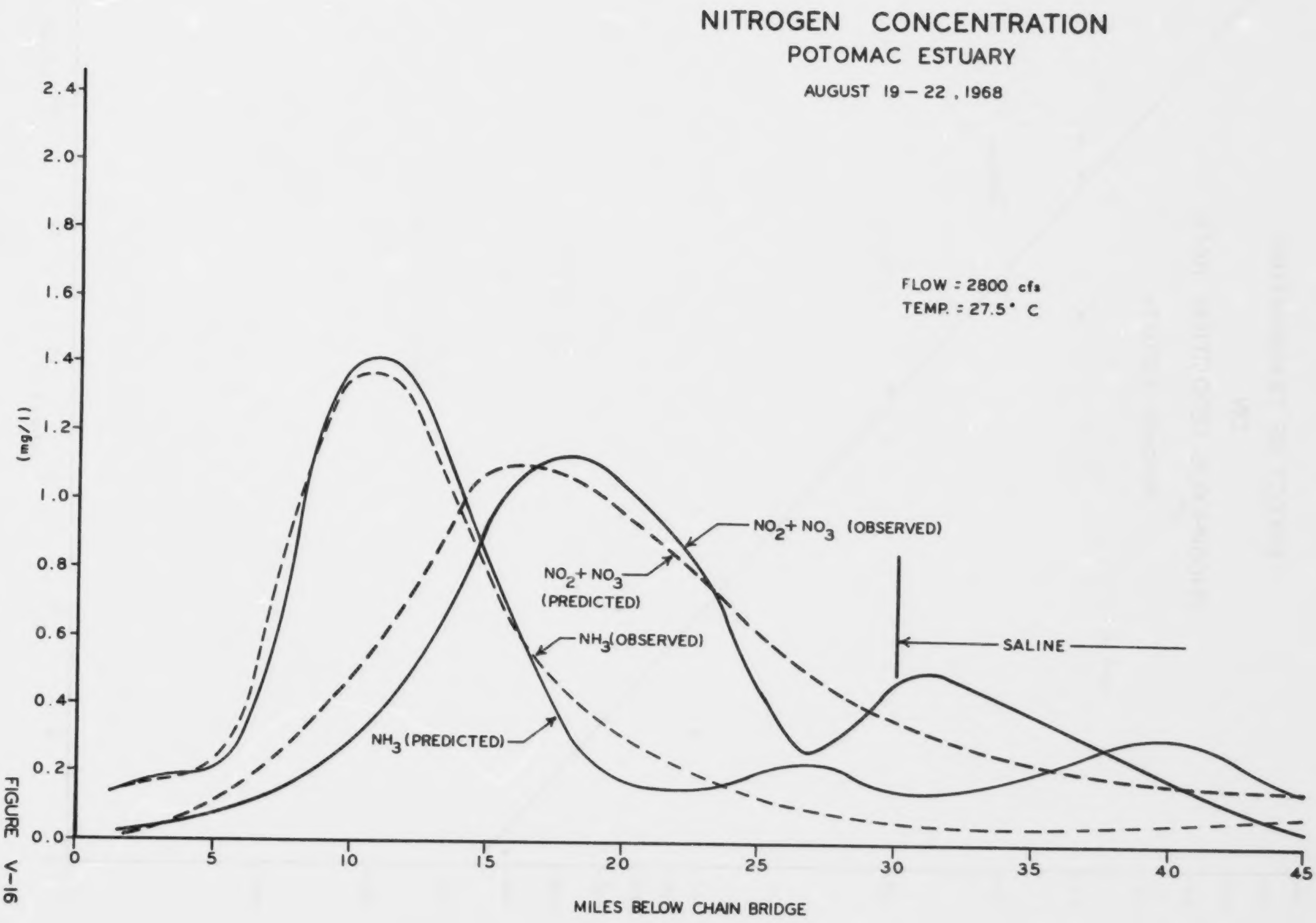
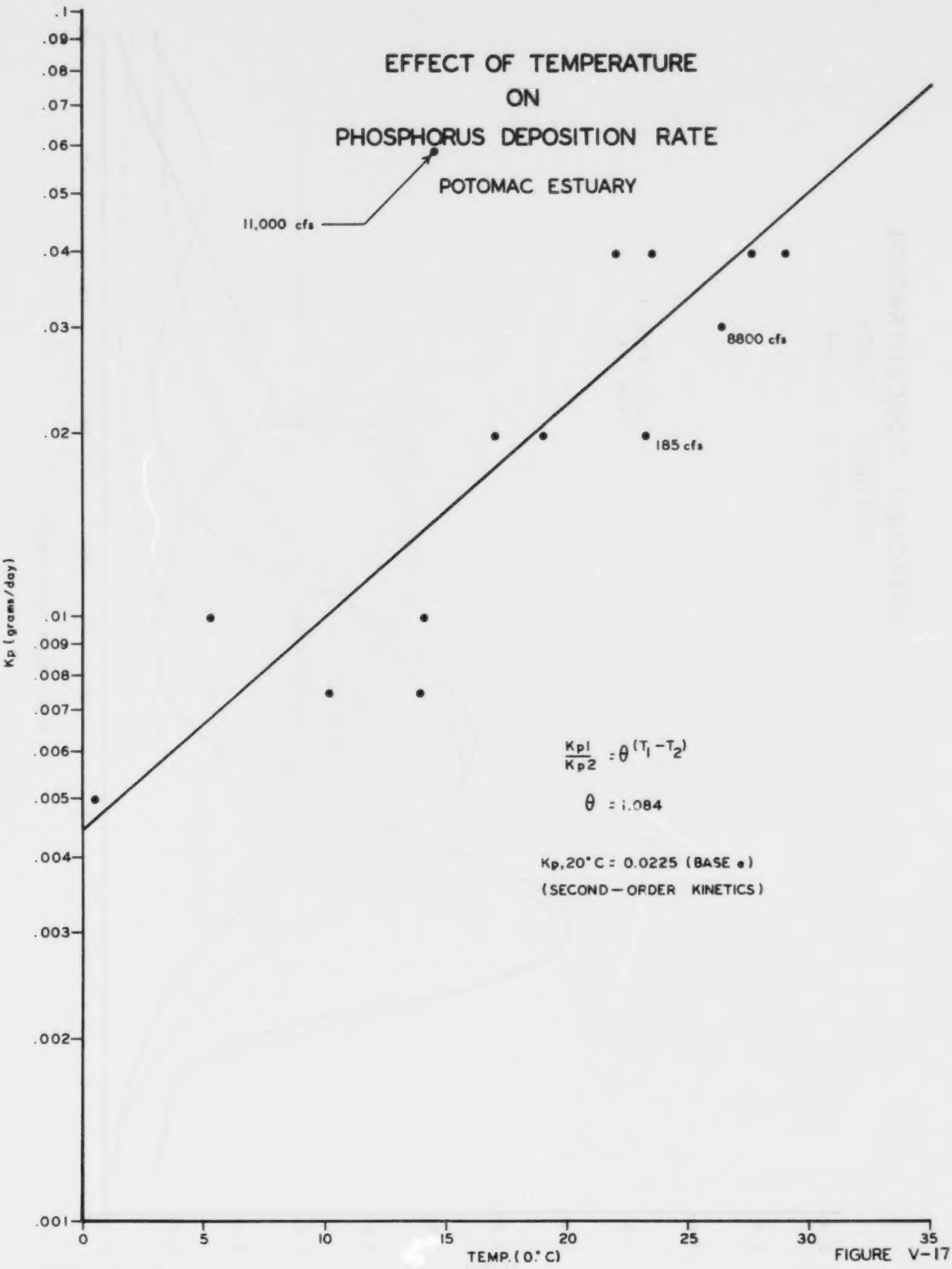

NITROGEN CONCENTRATION
POTOMAC ESTUARY
SEPT. 6-13, 1966
FLOW = 185 cfs
TEMP. = 23.7°C
$NO_2 + NO_3$ (OBSERVED)
$NO_2 + NO_3$ (MODEL PREDICTIONS)
SALINE
NH_3 MODEL PREDICTIONS
NH_3 (OBSERVED)
NITROGEN (mg/l)
2.4
2.2
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
0
5
10
15
20
25
30
35
40
45
MILES BELOW CHAIN BRIDGE

FIGURE V-15



NITROGEN CONCENTRATION
POTOMAC ESTUARY
AUGUST 19 – 22, 1968

FIGURE V-16



EFFECT OF TEMPERATURE
ON
PHOSPHORUS DEPOSITION RATE

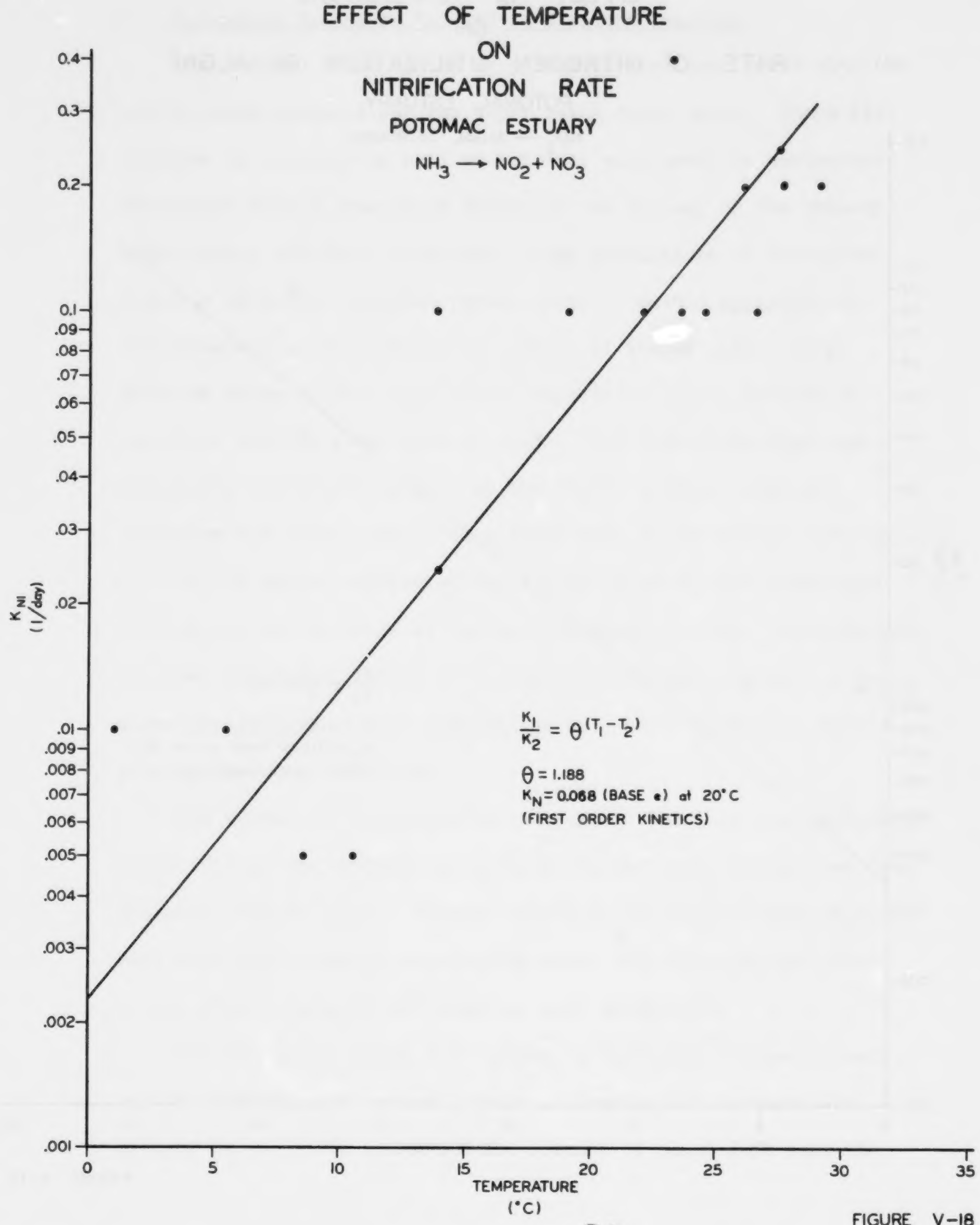
POTOMAC ESTUARY

$$\frac{Kp1}{Kp2} = \theta^{(T_1 - T_2)}$$

$\theta = 1.084$

Kp, 20° C = 0.0225 (BASE e)
(SECOND-ORDER KINETICS)

FIGURE V-17



EFFECT OF TEMPERATURE ON NITRIFICATION RATE

POTOMAC ESTUARY

$NH_3 \longrightarrow NO_2 + NO_3$

$$\frac{K_1}{K_2} = \theta^{(T_1 - T_2)}$$

$\theta = 1.188$

$K_N = 0.068$ (BASE e) at 20°C

(FIRST ORDER KINETICS)

FIGURE V-18

EFFECT OF TEMPERATURE ON RATE OF NITROGEN UTILIZATION BY ALGAE

POTOMAC ESTUARY

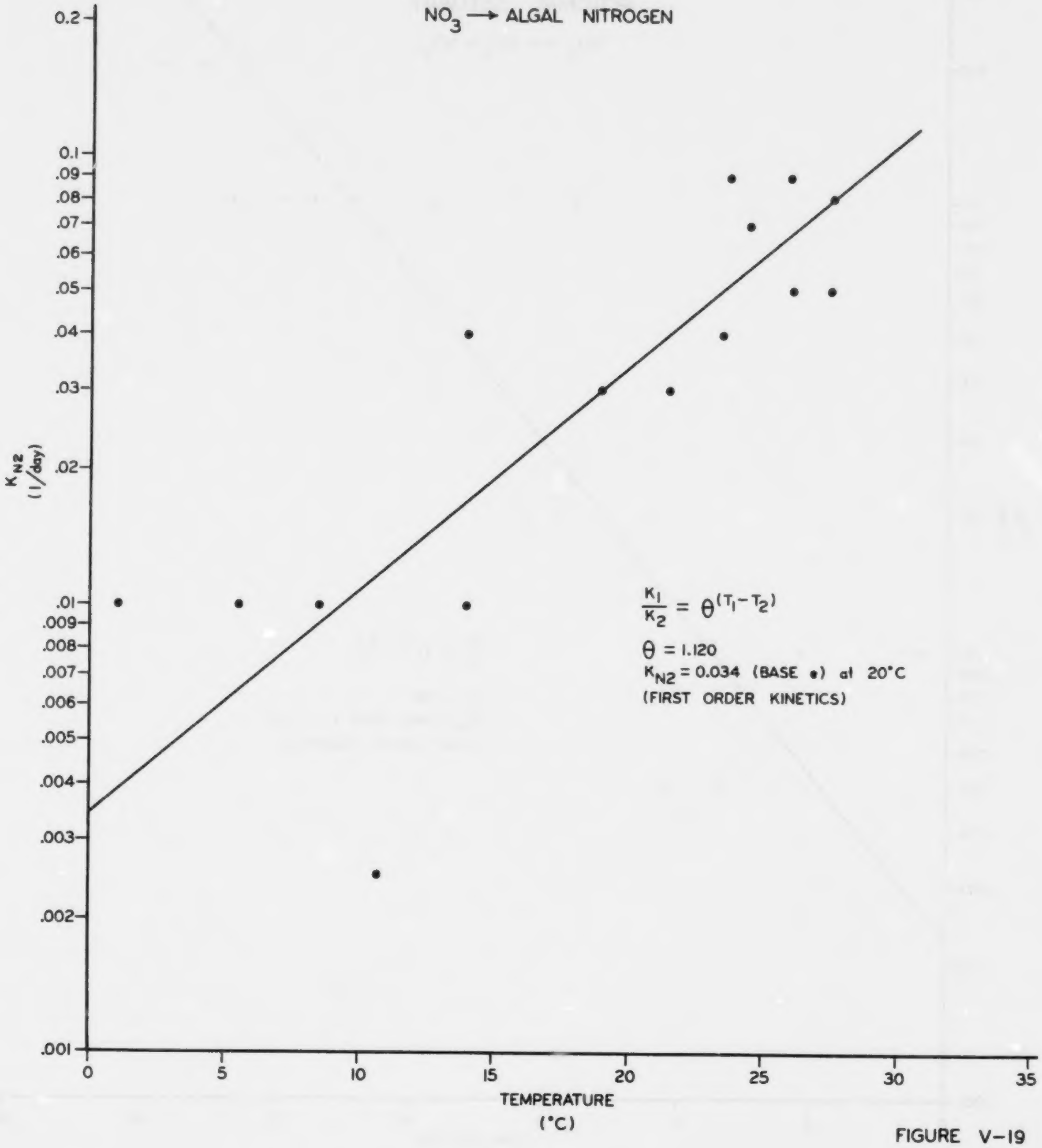


FIGURE V-19

3. Ecological Trends as Related to Nutrient Loadings

The Potomac tidal system is saline in the lower reach with the middle reach brackish and the upper reach fresh water. These differences in salinity as well as nutrient enrichment by wastewater discharges have a pronounced effect on the ecology of the estuary. Under summer and fall conditions, large populations of blue-green algae (a pollution tolerant phytoplankton), mainly *Anacystis* sp. are prevalent in the freshwater portion of the estuary. Large standing crops of this alga occur, especially during periods of low flow, forming green mats of cells. The blue-green algae are apparently not readily grazed by the higher trophic forms and therefore are often considered a "dead end" of the normal food chain.

In the saline portion of the Potomac Estuary, the algal populations are not as dense as in the freshwater portion. Nevertheless, at times large populations of marine phytoplankton, primarily the algae *Gymnodinium* sp. and *Amphidinium* sp., occur producing massive growths known as "red tides."

The effect of the increases in nutrient loadings from wastewater since 1913 on the dominant plant forms in the upper estuary has been dramatic (Figure V-20). Several nutrients and other growth factors have been implicated as stimulating this, with nitrogen and phosphorus showing promise of being the most manageable.

The historical plant life cycles in the upper Potomac Estuary can be inferred from several studies. Cumming [7] surveyed the estuary in 1913-1914 and noted the absence of plant life near the

WASTEWATER NUTRIENT ENRICHMENT TRENDS AND ECOLOGICAL EFFECTS

UPPER POTOMAC TIDAL RIVER SYSTEM

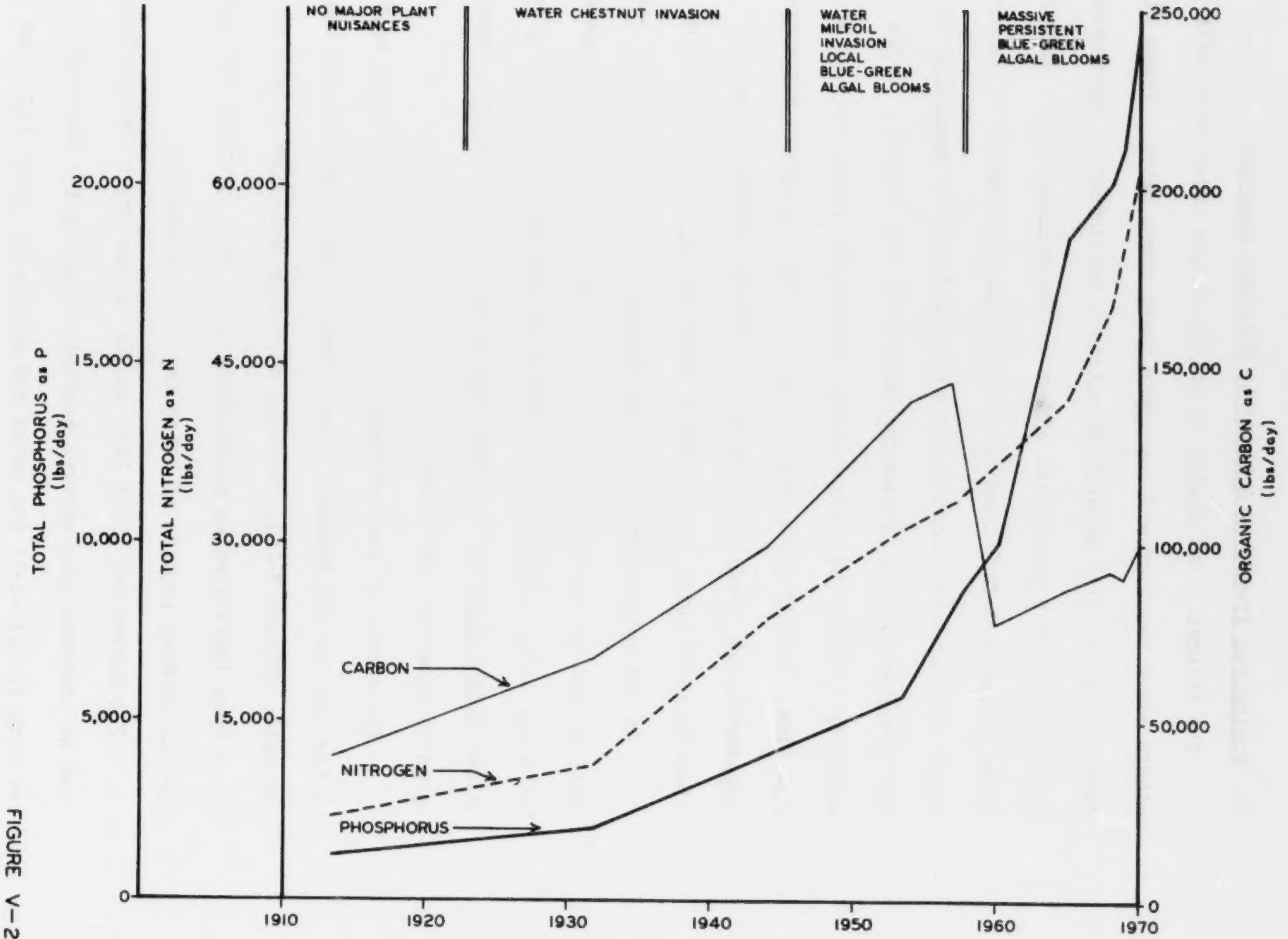


FIGURE V-20

major waste outfalls with "normal" amounts of rooted aquatic plants on the flats or shoal areas below the urban area. No nuisance levels of rooted aquatic plants or phytoplankton blooms were noted.

In the 1920's, an infestation of water chestnut appeared in the waters of the Chesapeake Bay including the Potomac Estuary. This infestation was controlled by mechanical removal [9].

In September and October 1952, another survey of the reaches near the metropolitan area made by Bartsch [10] revealed that vegetation in the area was virtually nonexistent. No dense phytoplankton blooms were reported although the study did not include the downstream areas where they were subsequently found.

In August and September 1959, a survey of the area was made by Stotts and Longwell [11]. Blooms of the nuisance blue-green alga Anacystis were reported in the Anacostia and Potomac Rivers near Washington.

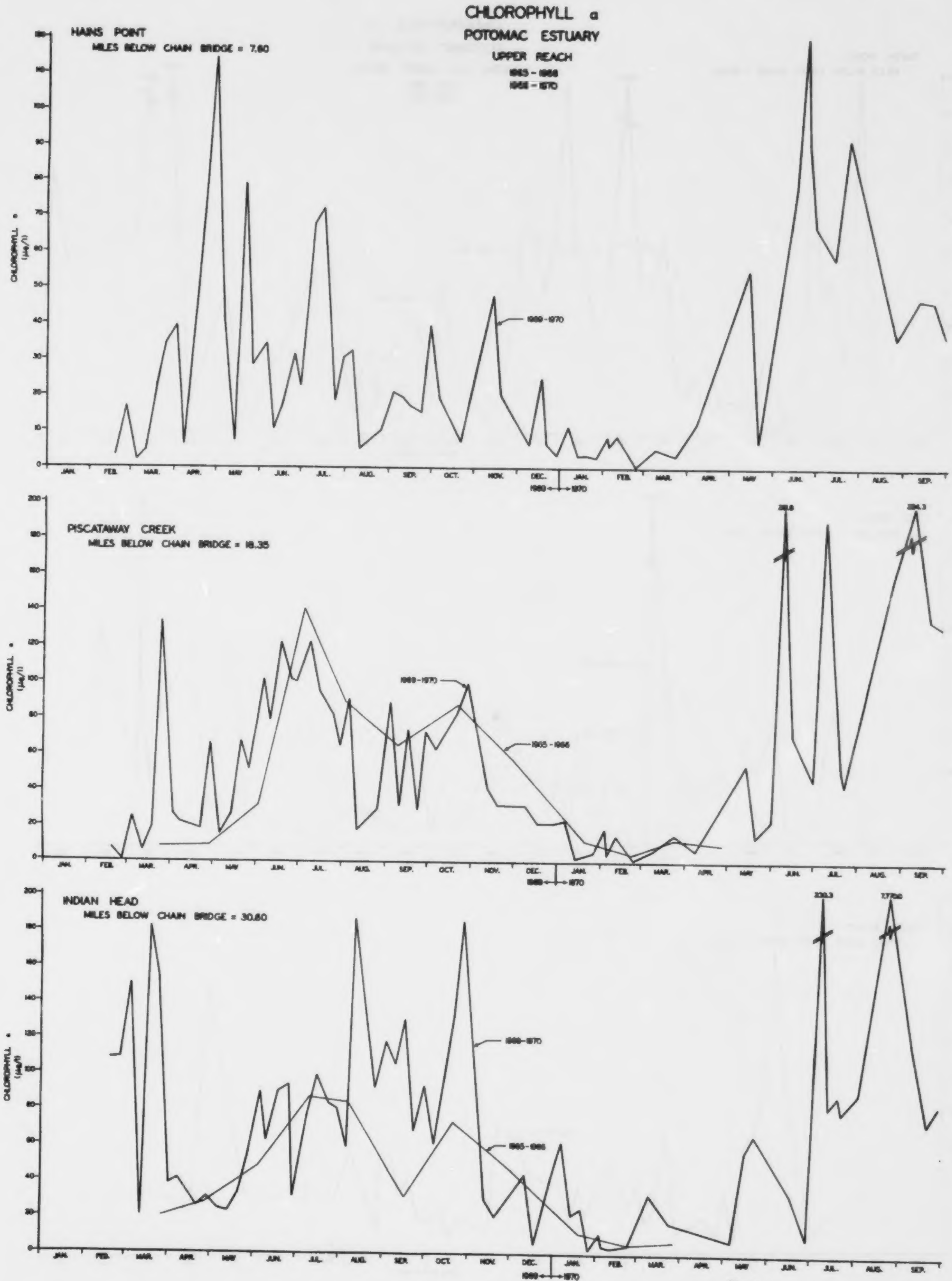
In 1958 a rooted aquatic plant, water milfoil, developed in the Potomac Estuary and created nuisance conditions. The growth increased to major proportions by 1963, especially in the embayments from Indian Head downstream [12].

These dense strands of rooted aquatic plants, which rapidly invaded the system, dramatically disappeared in 1965 and 1966. The decrease was presumably due to a natural virus [13].

Subsequent and continuing observations by CTSL have confirmed persistent massive summer blooms of the blue-green alga Anacystis in nuisance concentrations of greater than 50 ug/1 from the metropolitan area downstream at least as far as Maryland Point [14]. Chlorophyll a determinations (a gross measure of algal standing crop) in the upper reach and in the middle and lower reaches of the Potomac Estuary are presented in Figures V-21 and V-22 respectively.

Chlorophyll a at Indian Head and Smith Point for 1965-1966 and 1969-1970, as presented in Figures V-21 and V-22 respectively, indicate that algal populations have not only increased in density but have become more persistent over the annual cycle. At both stations, higher values of chlorophyll were measured during the 1969-1970 sampling cruises. The occurrence of a spring bloom of diatoms was observed in 1969 and 1970. This had not been observed during the 1965-1966 cruises.

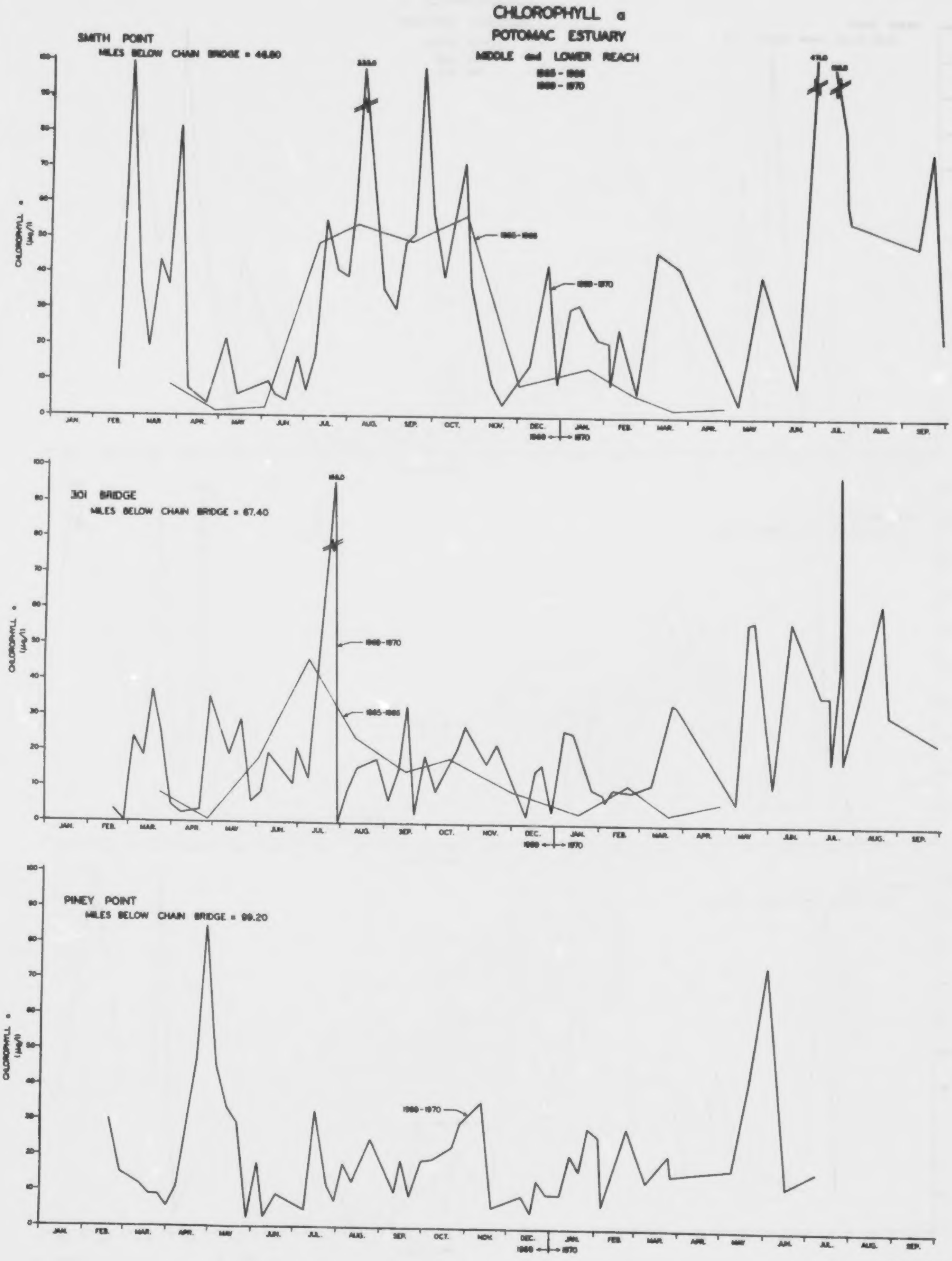
These biological observations over the years appear to indicate a species succession. The initial response to a relatively light overenrichment [9] was the growth of water chestnut which when removed allowed the increasing nutrient load to be taken up into the rooted aquatic plant, water milfoil (*Myriophyllum spicatum*). The die-off of water milfoil then allowed the nutrients to be competitively selected by the blue-green alga Anacystis. Since Anacystis is apparently not utilized in the normal food chain, huge mats and masses accumulate, die off, and decay.



CHLOROPHYLL a
POTOMAC ESTUARY
UPPER REACH
1965 - 1966
1969 - 1970

94

FIGURE V-21



CHLOROPHYLL a
POTOMAC ESTUARY
MIDDLE and LOWER REACH
1965 - 1966
1969 - 1970

FIGURE V-22

From the above considerations, it would appear that nuisance conditions did not develop linearly with an increase in nutrients. Instead, the increase in nutrients appeared to favor the growth and thus the domination by a given species. As nutrients increased further, the species in turn was rapidly replaced by another dominant form. For example, water chestnut was replaced by water milfoil which in turn was replaced by Anacystis.

Figure V-20 indicates that the massive blue-green algal blooms were associated with large phosphorus and nitrogen loading increases in the upper reaches of the Potomac River tidal system. The massive algal blooms have persisted since the early 1960's even though the amount of organic carbon from wastewater discharges has been reduced by almost 50 percent.

Laboratory and controlled field pond studies by Mulligan [15] have shown similar results. Ponds receiving low-nutrient additions (phosphorus and nitrogen) contained submerged aquatic weeds. Continuous blooms of algae appeared in the ponds having high nitrogen and phosphorus concentrations. An important observation in Mulligan's studies was that when the water quality was returned to its original state by reduction of nutrient concentrations, the ecosystem also reverted to its previous state. This observation was also supported by studies of Edmondson [16] on Lake Washington and Hasler on the Madison, Wisconsin lakes [17].

E. EFFECTS OF EUTROPHICATION ON WATER QUALITY

The effects of nutrient enrichment and the resulting algal growths are fourfold: (1) an increase in organic oxygen demanding load, (2) an increase or decrease in dissolved oxygen caused by algal photosynthesis or respiration, (3) the creation of nuisance and aesthetically objectionable conditions, and (4) the possible toxic effects on other plants and aquatic life. Each of the effects is discussed separately below:

1. Increase in Organic Oxygen Demanding Load

Algal cells convert inorganic carbon and nitrogen into organic compounds and result in an appreciable oxygen demanding load after their death. For example, under summer conditions, all of the 60,000 lbs/day of nitrogen discharged into the estuary from wastewater treatment facilities is converted into algal cells. The combined ultimate oxygen demand of nitrogen and carbon from these cells is approximately 490,000 lbs/day. This load, though dispersed over the entire upper estuary, is nevertheless greater than the total oxygen demand by all wastewater discharges into the upper estuary.

Laboratory studies on rate kinetics of the oxidation of algal cells at temperatures of $28^{\circ}C$ to $30^{\circ}C$ indicated that the reaction rates for the oxygen demanding process vary from 0.16 to 1.25 per day. The increase in organic oxygen demanding loads is often concentrated in the embayments or along the shores as a result of wind action. These concentrations of decaying algae produce noxious odors.

2. Algal Oxygen Production and Respiration

As shown in Figure V-7, the DO concentration in the Piscataway embayment was 12 mg/l which was about 4 mg/l above saturation capacity at the observed water temperature. This increase in DO above saturation capacity is due to oxygen produced by algal cells. The total oxygen production of a community as a result of the photosynthetic activity is a function of algal biomass and population composition, light intensity, and temperature. In the upper and middle Potomac Estuary, light penetration is usually limited to the upper 2 to 4 feet of the water column.

Bacterial and algal respiration occur simultaneously with the oxygen production process. Since the upper estuary is well mixed, this respiration process occurs over the entire water column. During the months of June and July 1970, oxygen production and respiration rate studies were made in the upper and middle Potomac Estuary as presented in Table V-3. A special respiration study was conducted on July 29, 1970, which indicated that .0010 mg O_2/hr/ug of chlorophyll respiration could be attributed to algae with the remainder due to bacterial and other oxidation processes.

With a euphotic zone of 2 feet, an average oxygen production of .010 mg O_2/hr/ug of chlorophyll for 12 hours/day, an average respiration of .0010 mg O_2/hr/ug of chlorophyll for 24 hours/day, and an average chlorophyll concentration of 100 ug/l, the oxygen balance for various water columns is given in Table V-4. The data indicate that for a

Table V-3

OXYGEN PRODUCTION AND RESPIRATION RATE SURVEY
Upper and Middle Potomac Estuary
1970

Date	Water Temp. (°C)	Chlorophyll a Range (ug/l)	Light Intensity Range (foot candles)	Oxygen Production mg/hr/ug of Chlorophyll a	Respiration mg/hr/ug of Chlorophyll a
6-22	26	40-110	250-300	.0073	.0023
6-23	27	70-120	200-300	.0084	.0011
6-24	27	54-110	200-300	.0087	.0024
6-25	27	50- 60	200-300	.0121	.0033
7-20	28	30-100	250-400	.0130	.0022
7-21	27	30-143	200-300	.0130	.0016
7-22	26	30-140	100-200	.0146	.0017
7-27	28	-	-	.0060	.0010

Table V-4

OXYGEN PRODUCTION-RESPIRATION BALANCES

Chlorophyll *a* = 100 ug/l
Oxygen Production = .010 mg/hr/ug chlorophyll for 12 hours/day
Respiration = .0010 mg/hr/ug chlorophyll for 24 hours/day

Water Column (depth)	Increase in Oxygen Averaged over Entire Water Column due to Photosynthesis (mg/l/day)	Decrease in Oxygen due to Respiration	Net (mg/l/day)
Euphotic Zone of 2.0 feet			
4	6.0	2.4	3.6
8	3.0	2.4	0.6
12	2.0	2.4	-0.4
16	1.5	2.4	-0.9
20	1.2	2.4	-1.2
Euphotic Zone of 4.0 feet			
4	12.0	2.4	+9.6
8	6.0	2.4	+3.6
12	4.0	2.4	+1.6
16	3.0	2.4	+0.6
20	2.4	2.4	0.0

water depth greater than 10 feet, respiration would be larger than production, thus resulting in a negative net balance on the oxygen resources of the system.

If the euphotic zone were increased to 4 feet, there would be a net oxygen production for water columns of 24 feet or less. Conversely, if the depth of the euphotic zone were 1 foot, there would be a net oxygen production for water approximately 6 feet and less in depth.

The DO budget in the Potomac Estuary is affected by algal production and respiration as shown in Figure V-23. The net result of oxygen production and demand by algal respiration and decay is a reduction of the oxygen resources. This DO depression is approximately 2.0 mg/l in the estuary and can be attributed to algal respiration and decay. The net oxygen production concept has been incorporated into the DO budget model for the Potomac Estuary.

DO CONCENTRATIONS
POTOMAC ESTUARY
AUGUST 19–22, 1968

FLOW = 2800 cfs
TEMP. = 27.5° C

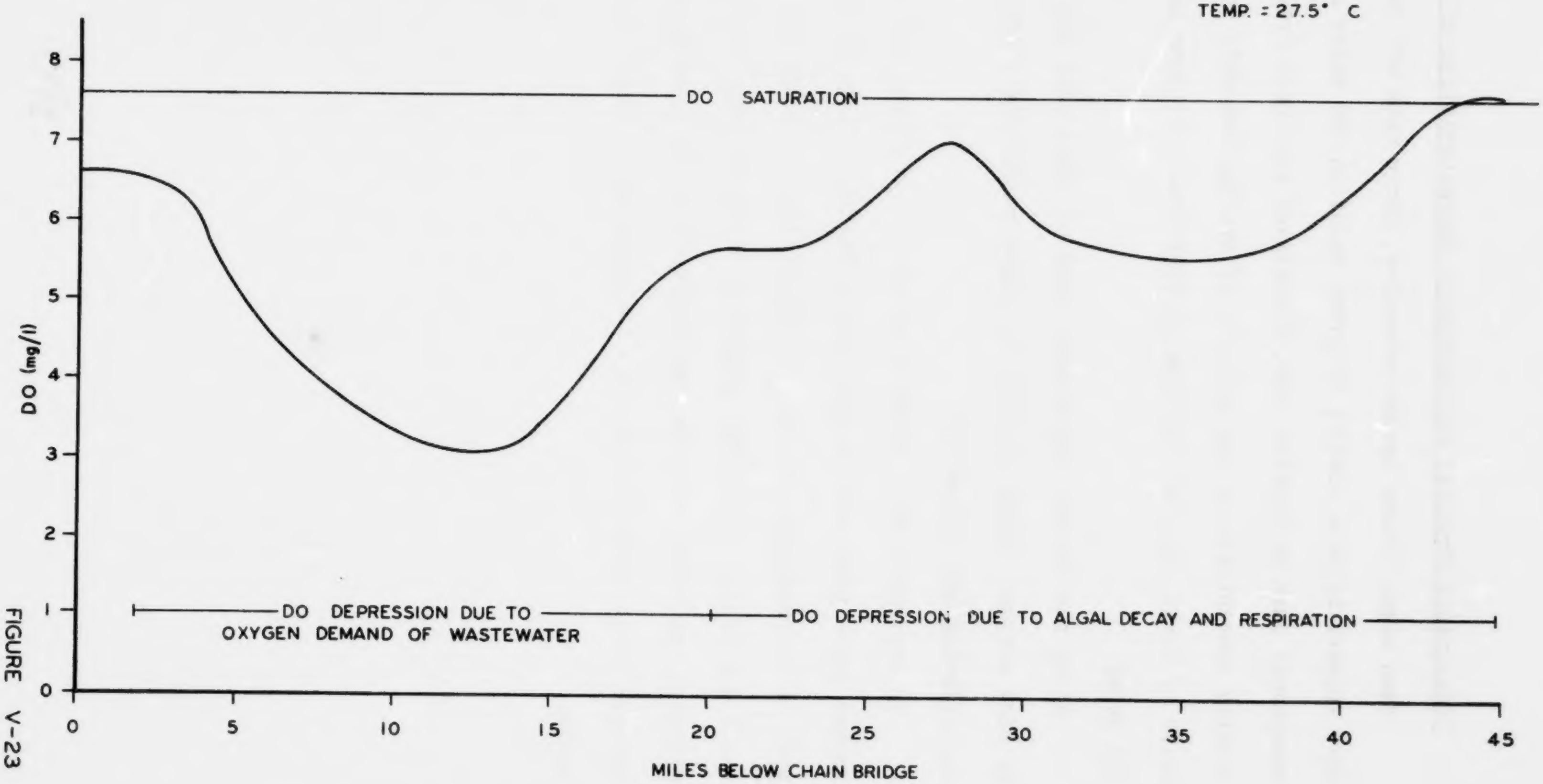


FIGURE V-23

3. Unfavorable Physical and Aesthetic Characteristics of Algal Blooms

When algal blooms become extensive, large mats are formed causing what appears to be a coating of green paint on the water surface. In embayments such as Gunston Cove, Piscataway and Dogue Creeks, these mats usually concentrate in the vicinity of marinas not only coating the hulls of boats but also emitting an obnoxious odor when the cells die and decay.

Along the Potomac shorelines, rows of algal mats are often formed by wind action. These windrows of algae render the shoreline unsuitable for swimming and recreation.

In September 1970, after a period of low flows, the algal blooms became quite prominent in the area of Woodrow Wilson Bridge. After a week of temperatures in the 90's Fahrenheit, an algal mat developed in the Tidal Basin. The dense growth of algae was physically removed to minimize the obnoxious odors emanating from the decaying mats. This was the first known occurrence of a heavy algal bloom in the Tidal Basin.

4. Algal Toxicity

It has been postulated that some algal species cause gastric disturbances in human beings who ingest infested water. Under certain conditions, several species of blue-green algae produce toxic organic compounds that can kill fish, birds, and domestic animals [21]. Of the 10 such known genera, three (Anabaena, Oscillatoria, and Anacystis) grow profusely in the upper Potomac Estuary.

At the present time, the effects of toxins from blue-green algae on other forms of life in the waters of the Potomac Estuary are not well established. In the summer of 1970, the blue crab harvest in an area of heavy algal blooms was reduced because of undesirable tastes and odors. It was also reported that several people became ill after eating crabs from this area. Crabbing in the lower Potomac, where there are no blue-green algal blooms, was not affected. It is postulated that the objectionable taste and odor of the crabs was related to the blue-green algae.

If the estuary is to be used as a water supply source, the possibility of the effect of toxins from blue-green algae must be considered. The genera currently found in the Potomac have known species which are toxin producers and as mentioned previously are also known to affect the taste and odor of seafood.

CHAPTER VI

DISSOLVED OXYGEN ENHANCEMENT

A. STUDY APPROACH

The concentration of dissolved oxygen in the upper estuary is a function of environmental conditions, biological population and activity, and concentration and composition of organic matter in the system. A schematic diagram shown in Figure VI-1, originally presented by Torpey [18], demonstrates the interrelationships of the oxidation of carbonaceous and nitrogenous components of organic matter by bacteria, and photosynthetic activity by phytoplankton, and dissolved oxygen.

The three biological systems having the greatest effect on the DO are the bacteria which oxidize the carbonaceous matter, the bacteria which oxidize the nitrogenous matter, and the phytoplankton which grow as a result of nutrient enrichment. In the upper Potomac Estuary, these three biological systems can and do occur simultaneously in the same area. The predominance of one or all of the three systems depends not only on the source of organic matter (wastewater effluents) but also on such environmental factors as temperature, light penetration, and freshwater inflow.

A DO budget has been incorporated into the FWQA Dynamic Quality Model consisting of the following five linkages:

(1) Oxidation of carbonaceous matter,

(2) Oxidation of nitrogenous matter (ammonia and organic),

A SCHEMATIC DIAGRAM OF
DISSOLVED OXYGEN INTERRELATIONSHIPS
FOR THE THREE
MAJOR BIOLOGICAL SYSTEMS

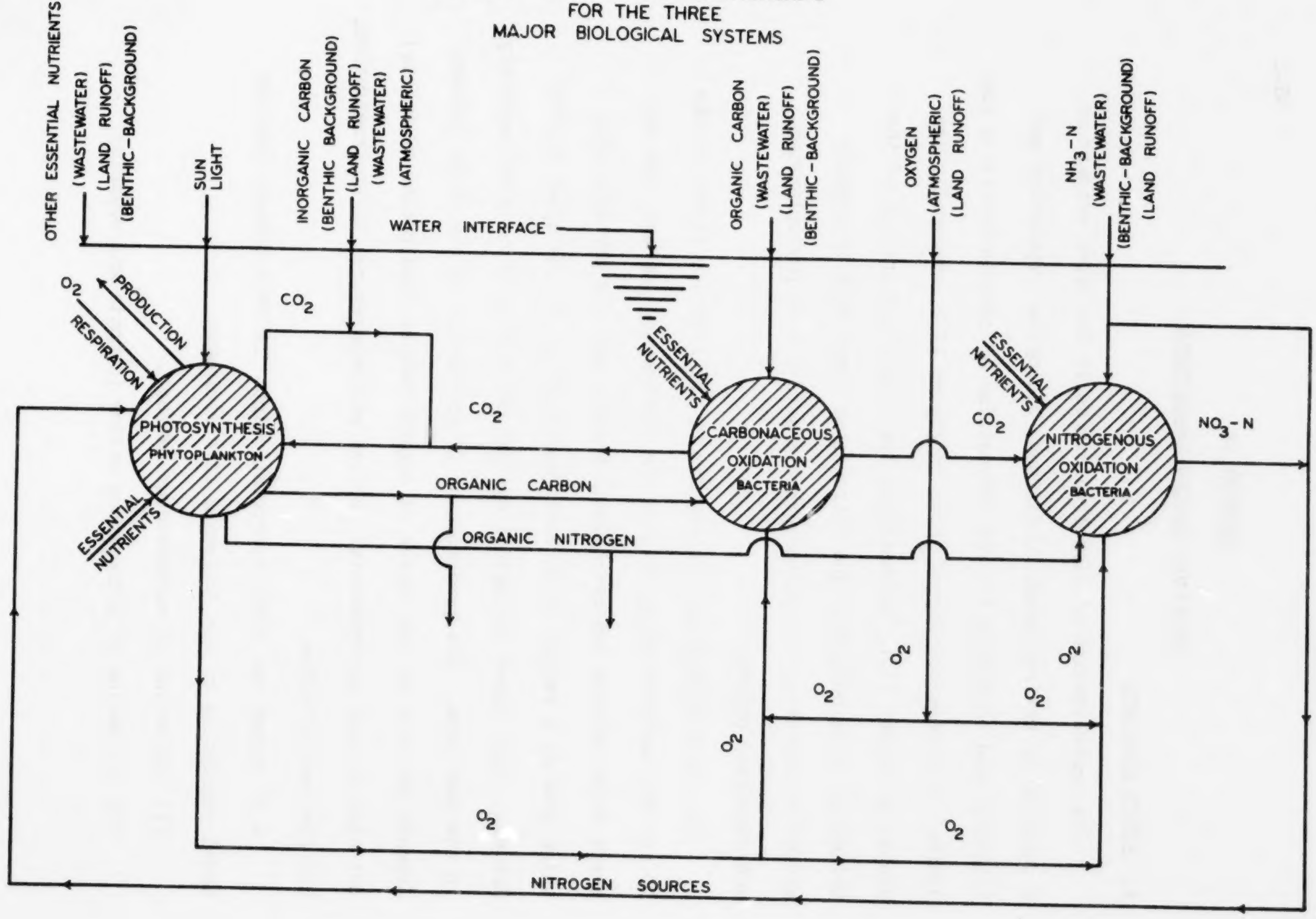

OTHER ESSENTIAL NUTRIENTS
(WASTEWATER)
(LAND RUNOFF)
(BENTHIC-BACKGROUND)
SUN LIGHT
INORGANIC CARBON
(BENTHIC BACKGROUND)
(LAND RUNOFF)
(WASTEWATER)
(ATMOSPHERIC)
WATER INTERFACE
ORGANIC CARBON
(WASTEWATER)
(LAND RUNOFF)
(BENTHIC-BACKGROUND)
OXYGEN
(ATMOSPHERIC)
(LAND RUNOFF)
NH$_3$-N
(WASTEWATER)
(BENTHIC-BACKGROUND)
(LAND RUNOFF)
O$_2$
PRODUCTION
RESPIRATION
CO$_2$
ESSENTIAL NUTRIENTS
PHOTOSYNTHESIS
PHYTOPLANKTON
CO$_2$
CARBONACEOUS
OXIDATION
BACTERIA
ESSENTIAL NUTRIENTS
CO$_2$
NITROGENOUS
OXIDATION
BACTERIA
ESSENTIAL NUTRIENTS
NO$_3$-N
ORGANIC CARBON
ORGANIC NITROGEN
O$_2$
O$_2$
O$_2$
O$_2$
O$_2$
O$_2$
O$_2$
NITROGEN SOURCES

FIGURE VI-1

(3) Oxygen production and respiration of simulated algal standing crops based upon nitrate utilization by the cells,

(4) Benthic demand, and

(5) Reaeration from the atmosphere.

The model, which is described in a CTSL report currently in preparation, has been verified for flow ranges from 212 to 8800 cfs. The average observed and predicted DO concentrations for the periods of September 22, 1968, and August 12-19, 1969, as shown in Figures VI-2 and VI-3 respectively, demonstrate that the model can predict DO responses over a wide range of freshwater inflows.

The basic coefficients used in the DO budget model are:

Process	Rate (base e) at 20°C	Temperature Coefficient $\theta^{(T_1 - T_{20})}$
Carbonaceous oxidation	0.170	1.047
Nitrogenous oxidation	0.068	1.188
Algal utilization of nitrogen	0.034	1.120
Reaeration from the atmosphere	*	1.021

The remaining processes in the DO budget are given below:

Algal oxygen production rate = 0.012 mg O_2/hr/ug chlorophyll a

Algal respiration rate = 0.0008 mg O_2/hr/ug chlorophyll a

Euphotic zone = 2 feet deep

Respiration depth = full depth of water column

Algal oxygen production period = 12 hours

Algal respiration period = 24 hours

Benthic demand rate = 1.0 gr O_2/day sq mi

* The model calculates reaeration as a function of depth and velocity using any one of three formulations.

DO CONCENTRATIONS
POTOMAC ESTUARY
SEPT. 22, 1968

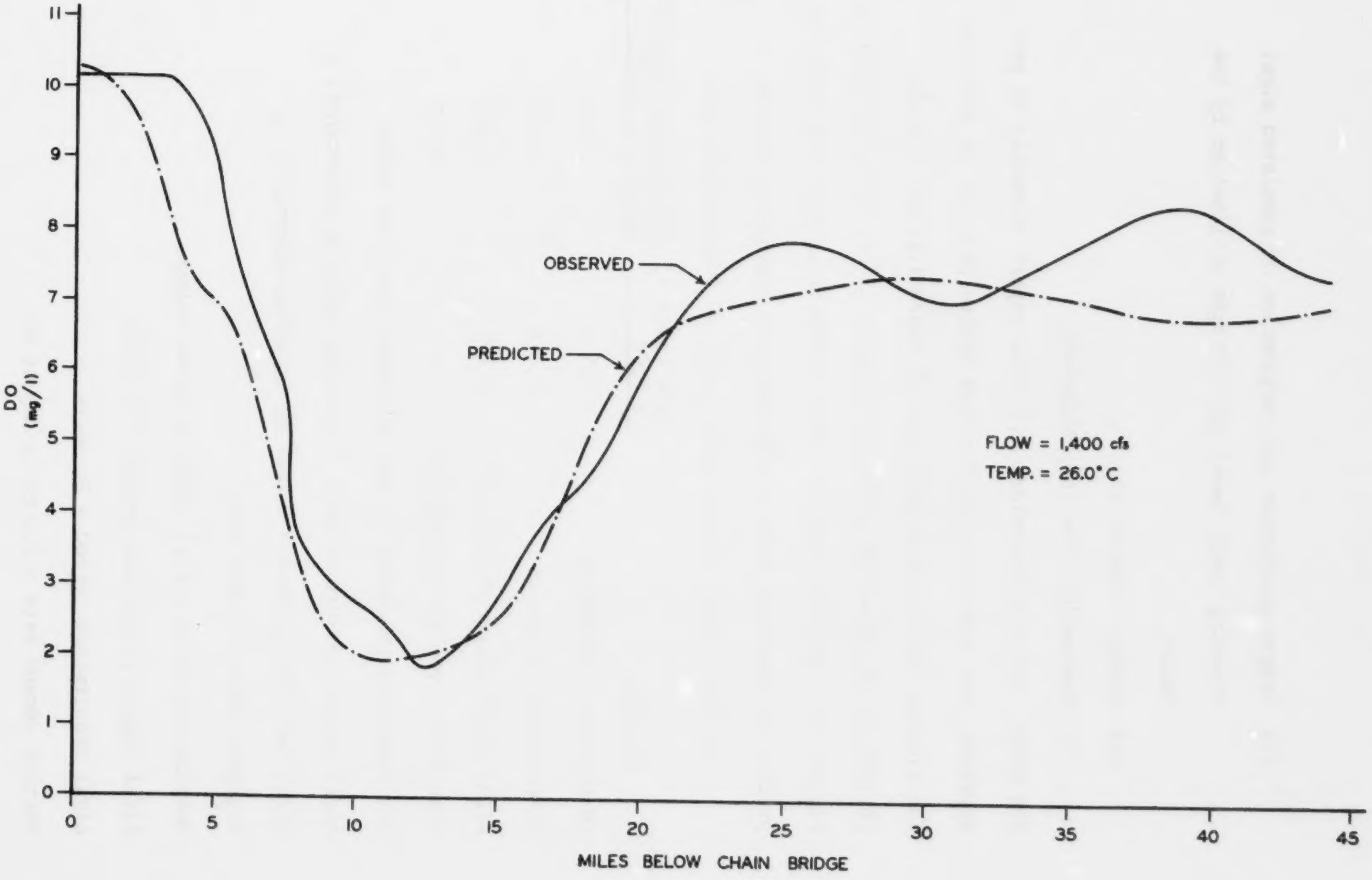


FIGURE VI-2

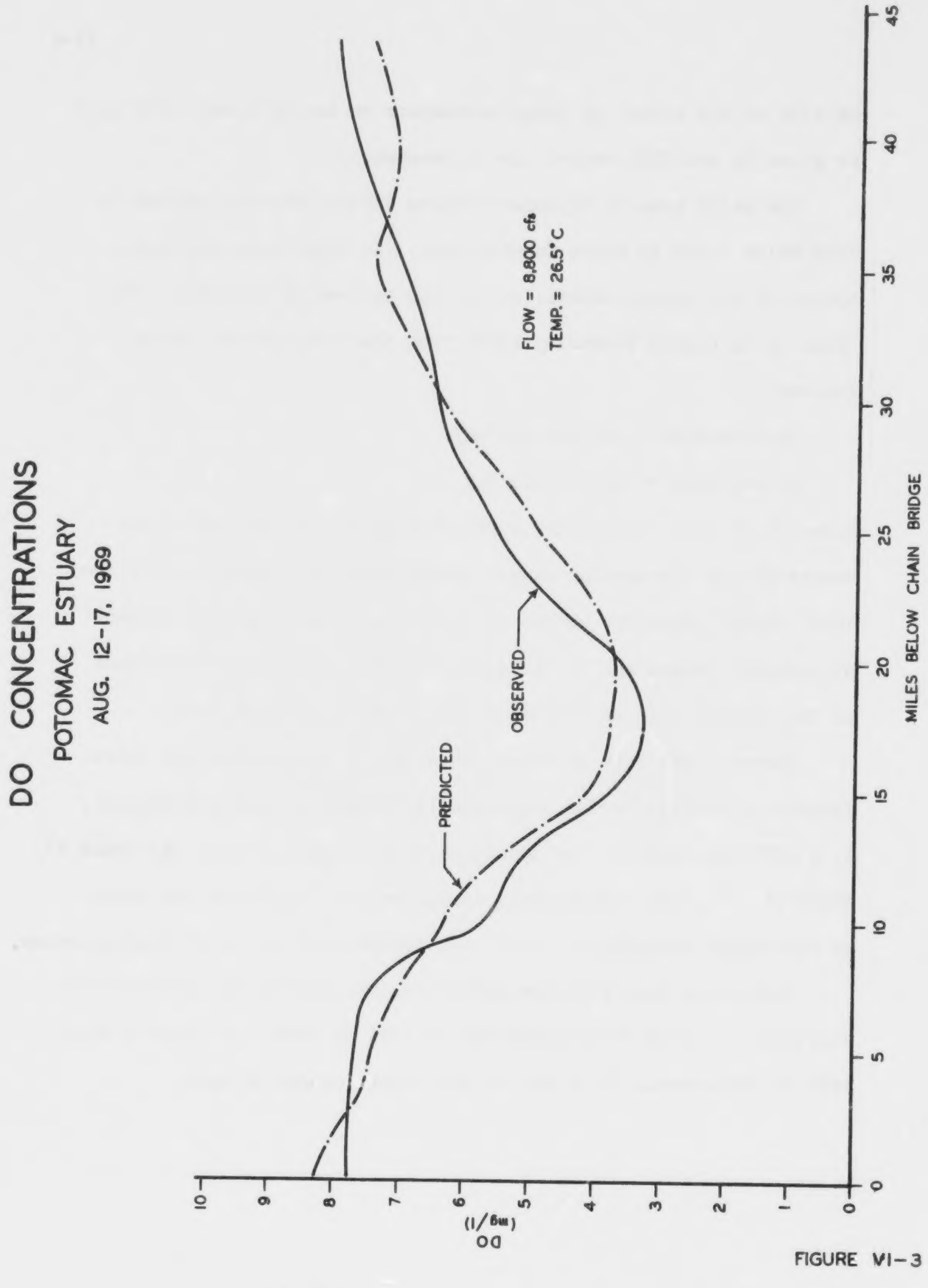

DO CONCENTRATIONS
POTOMAC ESTUARY
AUG. 12-17, 1969
FLOW = 8,800 cfs
TEMP. = 26.5°C
PREDICTED
OBSERVED
DO
(mg/l)
0
1
2
3
4
5
6
7
8
9
10
0
5
10
15
20
25
30
35
40
45
MILES BELOW CHAIN BRIDGE

FIGURE VI-3

Details of the effect of these parameters on the DO budget will also be given in the CTSL report now in preparation.

The major area of depressed oxygen during low-flow periods is from Hains Point to about Gunston Cove. In this area, the major source of the oxygen depression is from wastewater effluent. The total daily oxygen demanding loads from these discharges are as follows:

Carbonaceous = 200,000 lbs/day

Nitrogenous = 250,000 lbs/day

Under these flow conditions, approximately 65,000 lbs/day of carbonaceous and nitrogenous oxygen demand enter the upper estuary from land runoff. From the above, it can be concluded that the current nitrogenous demand has the greatest effect on the oxygen resources of the estuary with carbonaceous demand being slightly lower.

However, the rate at which the demand (carbonaceous and nitrogenous) is exerted varies significantly depending upon temperature. At a 28°C temperature, the demand rates are equal at 0.34 day (base e); while at 15°C, the carbonaceous demand rate is 0.18 with the nitrogenous demand dropping to 0.03. See Figure V-18 for nitrification rates.

Simulation runs with the model indicate that while nitrification continues to occur at temperatures of 15°C or lower, it plays a minor role in the overall DO budget of the upper Potomac Estuary.

For 22 years of record, mean monthly water temperatures in the upper estuary have been determined as given below:

January	2.5°C	July	28.1°C
February	3.3°C	August	27.8°C
March	7.8°C	September	24.7°C
April	14.0°C	October	18.4°C
May	20.4°C	November	11.5°C
June	25.9°C	December	4.8°C

Based upon the above tabulation and the study discussed above, it appears that nitrification control for DO enhancement is required only for the months of April through October. This is developed further in Chapter XII.

B. DO CRITERIA

Water quality standards for dissolved oxygen have been adopted by the States of Maryland and Virginia and by the District of Columbia.

For the waters of the Potomac, the standards are as given below:

Jurisdiction	Average DO (mg/l)	Minimum DO (mg/l)
District of Columbia*	5.0 (Daily)	4.0
State of Maryland	5.0 (Monthly)	4.0
State of Virginia	5.0 (Daily)	4.0

* Except between the Rochambeau Memorial and Prince Georges County (Maryland) line where the average is 4.0 and the minimum DO is 3.0.

These DO standards were used as criteria in this study.

CHAPTER VII

ALGAL GROWTH RESPONSE TO NUTRIENT CONTROL

Reductions in the standing crop (biomass) of algae in the Potomac Estuary can be achieved by management, singly or in combinations, of carbon, nitrogen, and phosphorus content. The decision as to which nutrient or nutrients to control may depend upon several factors especially the four listed below:

1. Level of algal reduction required to minimize the effect on water quality such as DO and recreational water use,
2. Maximum nutrient concentration allowable to maintain a maximum permissible algal standing crop,
3. Controllability and mobility of a given nutrient, and
4. The overall water quality objectives, such as DO enhancement, eutrophication reversal, or reduction of potentially toxic matter including heavy metals.

The four factors listed above were used not only to establish the nutrient criteria but also to develop the overall wastewater management program for the Potomac Estuary.

A. EUTROPHICATION CONTROL OBJECTIVES

For purposes of water quality management, the upper Potomac Estuary may be considered eutrophic when undesired standing crops become the predominant plant life as is now occurring with the nuisance blue-green alga species. The major objectives for controlling the blue-green algal standing crop in the upper estuary are fourfold:

1. To reduce the dissolved oxygen (DO) depression caused by respiration and the decay of algal growths especially in waters over 10 feet in depth. At times, DO depressions of more than 3.0 mg/l below saturation occur even during daylight hours.

2. To minimize the increase of ultimate oxygen demand (UOD) resulting from the conversion by algal cells of inorganic carbon and nitrogen from wastewater to oxidizable organic compounds. Currently, more UOD is added to the upper Potomac Estuary in the summer months as a result of algal growth than from wastewater discharges.

3. To enhance the aesthetic conditions in the upper estuary. Large green mats develop during the months of June through October and create objectionable odors, clog marinas, cover beaches and shorelines, and in general reduce the potential of the estuary for recreational purposes such as fishing, boating, and water skiing.

4. To reduce any potential toxin problem and objectionable taste and odor problems related to excessive blue-green algal crops if the upper estuary is to be used as a supplemental water supply.

To aid in defining an algal standing crop limit, a subjective analysis using chlorophyll concentrations was developed incorporating conditions having possible effects on water quality. Four major restraints to desired water uses are offered in this analysis (Table VII-1) including the required reduction in the chlorophyll standing crop for each of the parameters.

The desired maximum limit of 0.5 mg/1 DO below saturation was selected by CTSL to allow for assimilation of waste discharges and naturally occurring oxygen demanding pollutants. To minimize the effects of increased organic loads and sludge deposits caused by algal growths, an upper limit of 5.0 mg/1 of total oxygen demand is proposed.

Of the four restraints, the most stringent reduction percentage is for control of growths to prevent nuisance conditions. From the above analysis, a 75 to 90 percent reduction in chlorophyll concentration will be required in the Potomac Estuary, or chlorophyll levels of approximately 25 ug/1.

Table VII-1

SUBJECTIVE ANALYSIS OF ALGAL CONTROL REQUIREMENTS

Water Quality or Water Use Restraints	Indications of Restraints	Magnitude of Current Restraints*	Desired Maximum Limit	Required Percentage Reduction of Current Standing Crop
DO Depression Caused by Decay and Respiration	mg/1 of DO Below Saturation	1.5 to 3.0 mg/1	0.5 mg/1	65-85
Increase in Total Oxygen Demanding Load	mg/1 of Increase in Ultimate BOD	15 to 30 mg/1	5.0 mg/1	65-80
Recreational & Aesthetic Nuisance Conditions	Chlorophyll Concentration	> 100 ug/1	25 ug/1**	75-90
Toxins, Taste, & Odor	Undefined	Not Determined	Not Determined	Not Determined

* Under nuisance bloom conditions, chlorophyll a concentrations are greater than 100 ug/1

** Average over entire water column

B. NUTRIENT REQUIREMENTS TO PREVENT EXCESSIVE STANDING CROPS OF BLUE-GREEN ALGAE

Various investigators studying algal growth requirements have discussed the concentrations of nitrogen and phosphorus needed to stimulate algal blooms. In a recent study of the Occoquan Reservoir, located on a tributary of the Potomac Estuary, Sawyer [19] recommended limits of inorganic nitrogen and inorganic phosphorus of 0.35 and 0.02 mg/l, respectively. This reservoir has blue-green algal blooms under summer conditions attributed to wastewater effluents discharged into tributaries flowing into the reservoir. Mackenthun [20] cites data indicating upper limits of inorganic nitrogen at 0.3 mg/l and inorganic phosphorus at 0.01 mg/l at the start of the growing season to prevent blooms. FWQA's Committee on Water Quality Criteria recommends an upper limit of 0.05 mg/l of total phosphorus for estuarine waters [21]. No recommendations for inorganic nitrogen were made other than that the ratio of nitrogen to phosphorus should not be radically changed from that naturally occurring.

Pritchard [22], studying the Chesapeake Bay and its tributaries, suggests that if total phosphorus concentrations in estuarine waters are less than 0.03 mg/l, biologically healthy conditions will be maintained. Jaworski et al [14], reviewing historical data for the upper Potomac Estuary, suggest that if the concentration of inorganic phosphorus and inorganic nitrogen were at 0.1 and 0.3 mg/l respectively, algal blooms of approximately 50 ug/l of chlorophyll a would result. A chlorophyll a concentration of 50 ug/l or over was considered indicative of excessive algae. Studies of the James River Estuary, a sister estuary to the Potomac, by Brehmer and Haltiwanger [23] indicate that nitrogen appears to be the rate limiting nutrient.

Recently, the management of carbon in controlling algal blooms has been suggested by Kuentzel [24] and Lange [25]. Studies by Kerr et al [26] also suggest that inorganic carbon is apparently directly responsible for increased algal populations in waters they have studied. The Kerr studies indicate that the addition of nitrogen and phosphorus indirectly increases algal growth by stimulating growth of large heterotrophic populations. No concentration criteria for either nitrogen, phosphorus, or carbon were suggested to prevent excessive algal blooms.

In addition to the review of data cited above and other numerous articles not reported, six considerations were used to develop the nutrient requirements for the Potomac Estuary. The six were

1. Algal composition analyses,
2. Analysis of the nutrient data on an annual cycle and profile basis,
3. Nutrient bioassay,
4. Nutrient and algal mathematical modeling,
5. Comparison with an estuary currently not eutrophic, and
6. Review of historical nutrient and ecological trends in the Potomac Estuary.

A comprehensive approach to algal growth control was taken to include all three reaches of the estuary: the fresh water, the brackish, and the saline portions. In a study undertaken by Carpenter, Pritchard, and Whaley, oxygen concentrations of less than 1.0 mg/l were found in the area of the lower reach of the Potomac [27]. Comparable areas of the Chesapeake Bay, in terms of salinity and vertical stratification, did not show depletions to less than 1.0 mg/l. In terms of plankton counts and chlorophyll, their study indicated that the lower reach of the Potomac was more eutrophic than comparable waters of the Chesapeake Bay.

1. Algal Composition Analysis

In a previous chapter, the need to control algal growth was established. The three major nutrients in blue-green algal cells are carbon, nitrogen, and phosphorus. The chemical composition by weight of Anacystis, which is the most common algae in the Potomac as reported by Lawrence [21], is presented below:

Carbon	46.46%
Nitrogen	8.08%
Phosphorus	0.68%

Elemental analysis of the blue-green algae in the Potomac was made during the summer months of 1970 [53] and the data on carbon, nitrogen, and phosphorus ratios in terms of micrograms of chlorophyll a and grams of suspended solids are presented in Table VII-2. These data indicate that water with an algal bloom of 100 ug/l chlorophyll a contains the following:

Parameter	Concentration
S. Solids	14.2 mg/l
Carbon	4.5 mg/l
Nitrogen	1.0 mg/l
Phosphorus	0.1 mg/l (0.3 mg/l as PO_4)

Assuming that all nutrients can be utilized by the algal cells, an algal bloom with a concentration of 100 ug/l of chlorophyll a requires a minimum of 4.5 mg/l of carbon, 1.0 mg/l of nitrogen, and 0.10 mg/l of phosphorus (0.30 mg/l of PO_4) in the supporting water.

Table VII-2

ALGAL COMPOSITION STUDY

Upper Potomac Estuary
1970

Date	Sampling Location on Potomac	Carbon Ratio		Nitrogen Ratio		T. Phosphorus Ratio	
		mg carbon / ug chloro*	mg carbon / mg S.S.**	mg N / ug chloro	mg N / mg S.S.	mg PO$_4$ / ug chloro	Mg PO$_4$ / mg S.S.
7-20	Indian Head	.068	.379	.012	.066	.003	.016
7-20	Smith Point	.064	.366	.009	.062	.002	.016
7-24	Maryland Point	.058	.433	.006	.048	.002	.015
8-24	Sandy Point (Mallows Bay)	-	-	.008	-	.004	-
8-26	Sandy Point (Mallows Bay 1)	.044	-	.018	.033	.006	.011
8-26	Sandy Point (Mallows Bay 2)	.025	.199	.012	.095	.003	.022
8-26	Indian Head #1	.037	-	.009	-	.002	-
8-26	Indian Head #2	.025	.279	.012	.132	.003	.037
10-06	Indian Head	.055	-	.009	-	.002	-
10-06	Possum Point	.044	-	.006	-	.002	-
	AVERAGE	.045	.331	.010	.073	.003	.019

*Chloro = Chlorophyll a

**S.S. = Suspended Solids

***To convert PO$_4$ in mg/1 to P in mg/1 divide by 3.07

For the Potomac Estuary, which can be considered a slow-moving continuous culture system during the summer, a carbon concentration equal to or less than 1.1 mg/l, 0.25 mg/l of nitrogen, and 0.08 mg/l (0.027 mg/l as P) of phosphate would be theoretically required to maintain a 25 ug/l chlorophyll a level (or one quarter of the nutrient content in a bloom of 100 ug/l). These should be considered maximum concentrations since no recycling is assumed.

2. Analysis of Data on an Annual Cycle and Longitudinal Profile Basis

Using the disappearance of a specific nutrient both seasonally and along longitudinal profiles, insight can be gained as to the possibility of this nutrient becoming algal growth rate limiting. This assumes that other environmental factors do not restrict growth.

Figure V-10 in Chapter V shows that there was over 0.2 mg/l of available phosphorus as PO_4 in the critical reaches above Route 301 Bridge where there is substantial algal growth. From Indian Head to Smith Point, the area of pronounced algal growth, there was over 0.4 mg/l of inorganic phosphorus in the waters even under maximum bloom conditions. These data indicate that in the upper and middle reaches of the Potomac, phosphorus is in excess of 0.30 mg/l as PO_4 and thus not rate limiting. In the lower reach around Piney Point, the inorganic phosphorus was often as high as 0.1 mg/l and thus phosphorus could be limiting for this reach.

When the NH_3 and $NO_2 + NO_3$ concentrations shown in Figures V-11 and V-12 are reviewed, it is evident that in the later summer months practically all of the inorganic nitrogen had disappeared in the reach between the Smith Point and Route 301 Bridge stations by late July 1969 and by mid-August 1970. This depletion occurred even though the summers of 1969 and 1970 had relatively high flows. Based upon the disappearance of inorganic nitrogen, it appears that nitrogen becomes the major factor in limiting algal growth in the middle reach of the estuary.

To determine if carbon was limiting algal growth in the bloom area of the Potomac, total and organic carbon analyses were made during September 1970. (Flows during August and September 1970 were low with air temperatures reaching 95°F during the last week of September.) Dense algal blooms extended from Hains Point to Smith Point. Carbon concentrations obtained during a sampling cruise on September 20, 1970, were as follows:

Station	Organic Carbon (mg/1)	Inorganic Carbon (mg/1)
Hains Point	7.2	12.2
Wilson Bridge	10.5	15.4
Piscataway	10.5	8.6
Indian Head	10.5	15.0
Smith Point	8.5	7.7
Route 301 Bridge	6.1	6.1

The above data, which were obtained during the mid-day hours of September 20, 1970, indicate that there were large quantities of inorganic carbon available for algal growth. As reported earlier, with the free carbon dioxide in the water ranging between 6.0 and 10.0 at the point of maximum growth (Indian Head), it appears that there is an excess of inorganic carbon available for algal growths.

A review of nutrient data for the summer of 1965 yielded similar results. As can be seen in Figure VII-1, there was complete utilization of nitrate nitrogen between March and August by biota in the Potomac

NUTRIENT-CHLOROPHYLL PROFILES

POTOMAC ESTUARY

MARCH — AUGUST, 1965

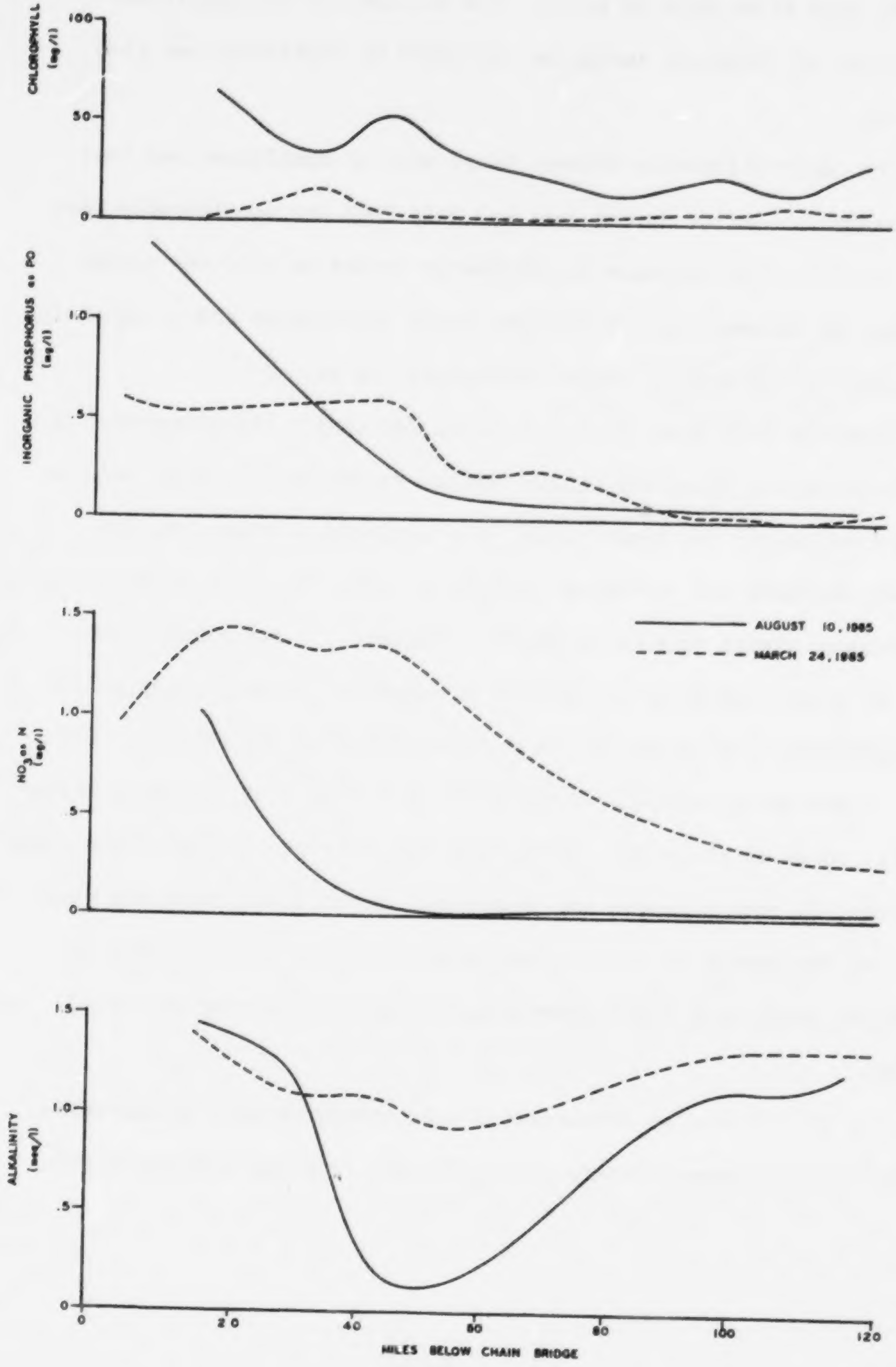


FIGURE VII-1

Estuary from River Mile 20 to 60. The utilization of significant quantities of inorganic carbon as indicated by alkalinity was also observed.

The basic difference between these sets of conditions was that the freshwater inflow during June and July 1965 was considerably less than in 1970. The increase in freshwater inflow in 1970 was enough to keep the Potomac high in nitrogen until late August and to maintain a minimum of 5.0 mg/l of carbon throughout the estuary.

From the 1965 data, it can be concluded that: (1) phosphorus is excessive in the upper and middle reaches of the estuary with very low concentrations in the lower reach, (2) inorganic nitrogen has the largest decrease and virtually disappears, with the lower 60 miles of the estuary almost void of nitrogen in August, (3) the significant loss of total alkalinity (a measure of inorganic carbon) occurred in approximately 15-20 miles of the middle portion of the estuary. However, there was a residual of about 3.0 to 5.0 mg/l of inorganic carbon, and (4) based on the above, it appears that nitrogen in the middle reach and possibly both nitrogen and phosphorus in the lower reach was controlling the growth of algae. All three nutrients are in excess in the upper reach with light penetration being the limiting factor of growth.

The 1965 data also demonstrated that another source of inorganic carbon to the Potomac Estuary is recruitment from the Chesapeake Bay.

This source of inorganic carbon appears to be a very important part of the entire carbon balance especially in the middle and lower portion of the estuary. In this area, which as previously indicated is more eutrophic than comparable areas of the Chesapeake Bay, the control of algae may be limited to management of nitrogen and phosphorus.

3. Bioassay Studies

To determine further what nutrients were limiting algal growth in the Potomac, bioassay tests as developed by Fitzgerald [28] [29] were employed. Tests for both phosphorus and nitrogen were conducted in the Potomac from Piscataway Creek to Route 301 Bridge for the period June through October 1970.

Using the rate of ammonia absorption by algal growths, it is possible to determine if the algal cells have surplus nitrogen or if they are nitrogen starved. Tests made during June and early July indicate that ammonia was either released or absorbed at a low rate in the range of 10^{-6} mg N/hr/ug chlorophyll a. The cells had adequate nitrogen available for growth as was also indicated by the high nitrate concentration in the water, especially at the upper stations above Indian Head.

Bioassay tests for October 13, 1970, as tabulated below, show a significant increase in ammonia absorption rates between the Piscataway station and the Smith Point station farther downstream.

Table VII-3

NITROGEN BIOASSAY SUMMARY
Potomac Estuary
1970

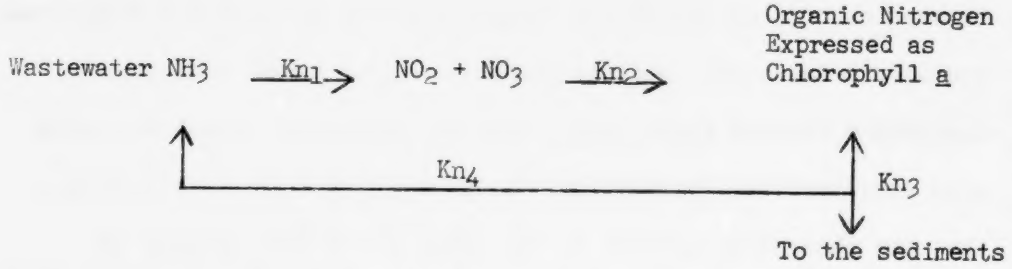
Station	NH_3 In Water (mg/1)	$NO_2 + NO_3$ In Water (mg/1)	Ammonia Nitrogen Absorbed (mg N/hr/ug chloro)
Piscataway	.110	2.560	+ 6.0×10^{-5}
Indian Head	.150	.684	+ 6.0×10^{-5}
Possum Point	.001	.220	+ 2.3×10^{-4}
Smith Point	.001	.150	+ 1.3×10^{-4}

The higher rates of ammonia absorption for Possum and Smith Points and the low concentration of inorganic nitrogen indicate that this reach of the Potomac is becoming nitrogen limited.

Two tests, an extraction and an enzymatic analysis [29], were used to determine if algal growth was phosphorus limited. The phosphorus extraction bioassay studies indicated very little difference between amounts of phosphorus released at the upstream and downstream stations. Tests for alkaline phosphatase, an enzyme indicator of phosphorus starved algal cells, were all negative. These two tests also confirmed the observation, discussed in the previous section, that the phosphorus content in the upper and middle estuary was excessive (over 0.15 mg/l as P).

4. Nutrient and Algal Modeling

Recognizing the possibility that the Potomac becomes nitrogen starved in late summer, an attempt was made to surrogately mathematically model algal growth based on the nitrogen cycle. The model, similar to that proposed by Thomann et al [30] is a feedback system as shown below:


Wastewater NH_3
Kn_1
$NO_2 + NO_3$
Kn_2
Organic Nitrogen
Expressed as
Chlorophyll a
Kn_4
Kn_3
To the sediments

This system was incorporated into the dynamic estuary model [41] and was utilized to establish the first-order rates for the feedback system for summer conditions. The established rates (base e) are:

Kinetic Reaction	Rates	
Kn_1	.30 - .40	(per day)
Kn_2	.07 - .09	(per day)
Kn_3	.01 - .05	(per day)
Kn_4	(not established)	(per day)

The first two reactions including the rates Kn_1 and Kn_2 have been fairly well verified as reported earlier and as shown in the predicted profiles of NH_3 and $NO_2 + NO_3$ in Figures V-15 and V-16. The feedback link appears to play a minor part in the system during the earlier summer months.

Predicted profiles using the surrogate algal model, as shown in Figures VII-2 and VII-3, matched the observed data quite closely with respect to location of maximum concentration and general shape of the profile. Other model predictions and a complete description of the model are also currently being prepared by CTSL.

From these mathematical model runs, it appears that the standing crop of the blue-green alga can be predicted using the nitrogen cycle. This further supports the premise that the availability of nitrogen appears to be controlling the standing crop of algae.

Using the model and the August 19-23, 1968, data as shown in Figure VII-2, the reduction of chlorophyll a concentrations to 25 ug/l would result in a maximum $NO_2 + NO_3$ concentration of 0.25 mg/l. For the September 6-9, 1966, data as shown in Figure VII-3, an upper limit of 0.38 mg/l of nitrogen would be required to reduce the chlorophyll level to 25.0 ug/l. From the modeling analysis, it appears that if the inorganic nitrogen is between 0.2 and 0.4 mg/l the blooms can be held below the maximum level of 25 ug/l of chlorophyll a.

CHLOROPHYLL CONCENTRATION
POTOMAC ESTUARY
AUGUST 19-23, 1968

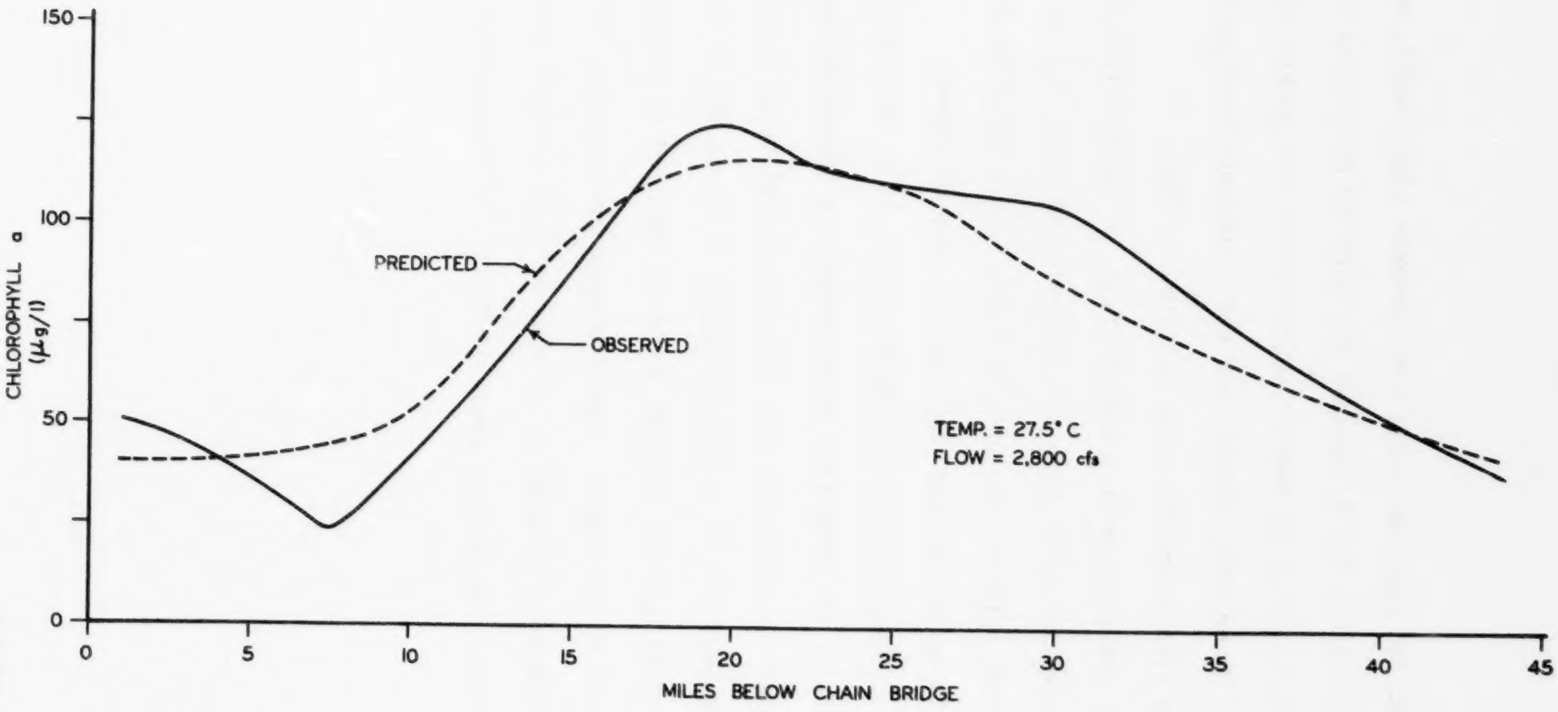


FIGURE VII – 2

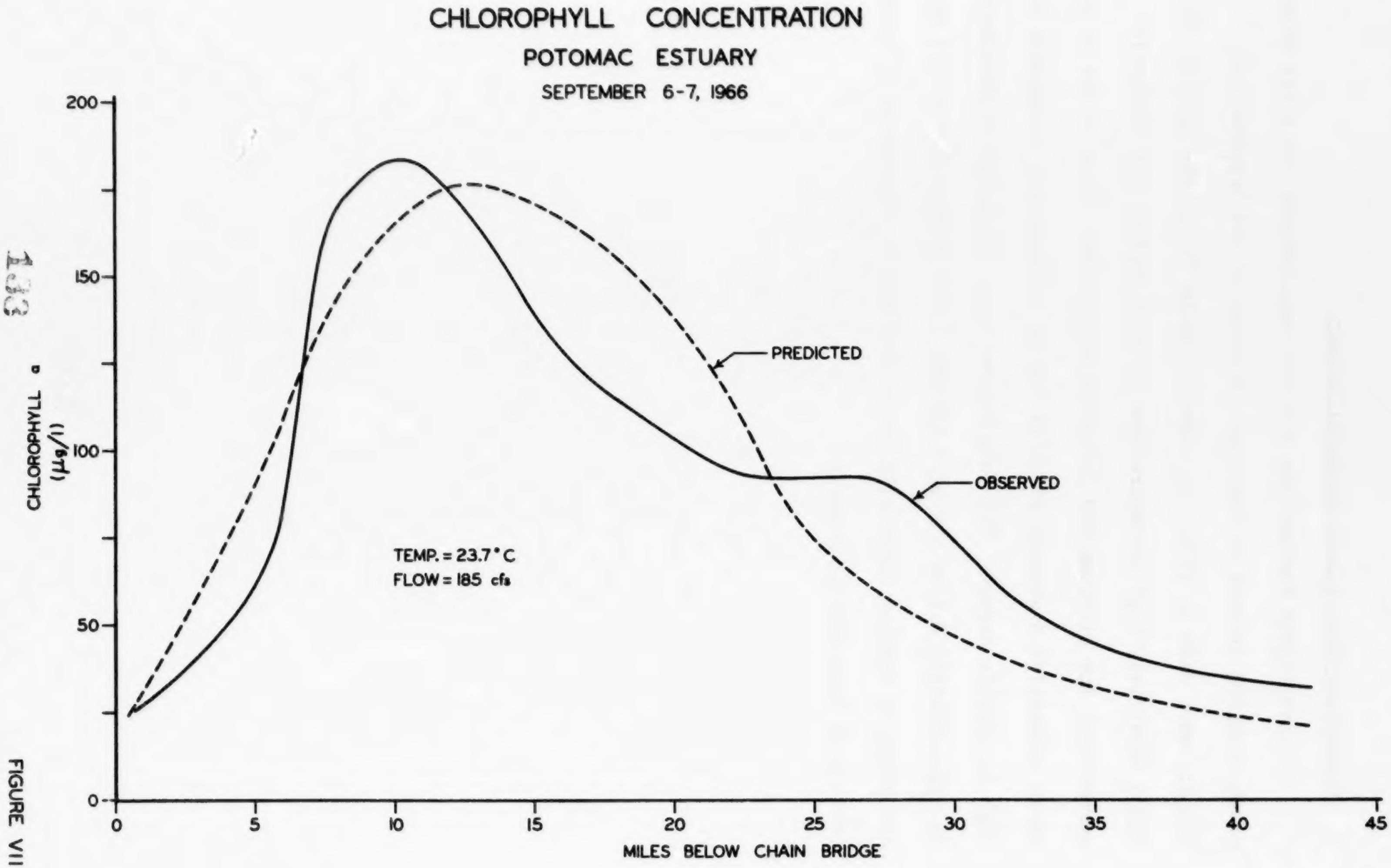

CHLOROPHYLL CONCENTRATION
POTOMAC ESTUARY
SEPTEMBER 6-7, 1966
CHLOROPHYLL a
(μg/l)
200
150
100
50
0
0
5
10
15
20
25
30
35
40
45
MILES BELOW CHAIN BRIDGE
PREDICTED
OBSERVED
TEMP. = 23.7° C
FLOW = 185 cfs

FIGURE VII-3

5. Comparison With a Less-Stressed Estuary

To investigate further the nutrient requirements for algal growth, seven sampling cruises of the upper 30 miles of the Rappahannock Estuary were made in 1970. As shown in Table VII-4, the estuary contains relatively high concentrations of both organic and inorganic carbon with low nitrates and inorganic phosphates. This is due in part to an industrial discharge which is low in nitrogen and phosphorus but high in organic carbon. The data suggest that if inorganic phosphate is approximately 0.1 to 0.2 mg/l and NO_2 + NO_3 between 0.1 to 0.3 mg/l, the standing crop of algae will be minimal with a chlorophyll a concentration of less than 40.0 ug/l.

Table VII-4

SUMMARY DATA
Upper Rappahannock Estuary
1970

Date	Inorganic P as PO_4 (mg/l)	$NO_2 + NO_3$ (mg/l)	Chloro **a** (ug/l)	Organic Carbon (mg/l)	Inorganic Carbon (mg/l)
6-23	0.13	0.26	32	7.3	No Data
6-30	0.18	0.12	34	No Data	No Data
7-07	0.10	0.11	40	No Data	No Data
7-13*	0.38	0.64	8	7.8	No Data
7-21	0.15	0.27	70	5.0	5.0
7-29	0.22	0.39	17	9.7	4.8
8-28	0.14	0.21	39	17.9	No Data

* High river discharge

6. Review of Historical Nutrient and Ecological Trends in the Potomac Estuary

As reported in Chapter V, there appears to be a definite relationship between the ecological and nutrient enrichment trends in the upper Potomac (Figure V-20). Prior to the 1920's, the phosphorus loading was 1,100 lbs/day or 4 percent of today's loading. Similarly, the nitrogen loading was 6,400 lbs/day or 10 percent of today's wastewater contribution.

The concentration in the upper estuary under summer conditions for the period before 1920 was estimated to be 0.12 to 0.20 mg/1 of PO_4 with inorganic nitrogen ranging from 0.15 to 0.30 mg/1. With a reversion to these concentrations, not only should there be a significant reduction in the blue-green algal population, but there should also be a general reversal in the ecological community succession.

C. CONTROLLABILITY OF VARIOUS NUTRIENTS

As discussed previously, the three major sources of nutrients in the upper estuary are ---- (1) wastewater discharges, (2) the upper basin, and (3) Washington urban and suburban drainage.

For the 7 months during which algal growths are most prolific and affected by changes in nutrient contributions, the percentages of phosphorus, nitrogen, and carbon attributable to wastewater discharges are listed below:

Month	Mean Monthly Flow (cfs)	Percentage Currently from Wastewater Discharges		
		Phosphorus	Nitrogen	Carbon
April	20,000	60	26	17
May	14,500	67	36	20
June	8,700	76	50	26
July	5,500	83	63	33
August	6,000	82	61	31
September	4,700	84	66	35
October	6,300	81	59	29

From the above tabulations, it can readily be seen that not only can phosphorus be controlled by removal to the highest degree (percentage removal) at the wastewater treatment facility, but phosphorus can be controlled earliest in the growing season. These two aspects enhance the feasibility of phosphorus management.

While 82 to 96 percent of the phosphorus entering the upper estuary can be controlled by removal at the wastewater treatment facilities during median to low flows [52], an additional reduction of phosphorus concentration occurs during periods of high runoff within the upper estuary itself. As reported by Aalto et al [8], large quantities of phosphorus (over 100,000 lbs/day) enter the upper estuary during high-flow periods at concentrations over 0.5 mg/1 (1.5 mg/1 as PO_4) during the rising portion of the river discharge hydrograph. However, high silt concentrations also accompany high flows. Large amounts of phosphorus are sorbed upon the silt particles and removed from the water system as sedimentation occurs in the upper reach of the estuary.

Although there was some dilution of high phosphorus concentrations, the large sediment load reduced the overall phosphorus concentration by a minimum of 20 percent in the reaches upstream and downstream from the major wastewater sources [52]. This reduction during periods of high flow would tend to add to the controllability of phosphorus as tabulated earlier. The high percentage from wastewater discharges, especially during the early months of the algal growing season and the large losses to the sediments during high-flow periods made phosphorus an ideal nutrient to manage.

The tabulation also indicates that over 60 percent of the nitrogen originates in the wastewater discharges during the critical months of July through October. The previous table does not include nitrogen recruitment from the atmosphere or by either bacterial or algal fixation. Hutchinson [31] reported that about 5 lbs/acre/year of nitrogen is drawn from the atmosphere. Using this rate for the upper 60 miles of the Potomac Estuary, about 1,600 lbs/day of nitrogen is obtained from the atmosphere as compared to over 50,000 lbs/day from wastewater discharges. Thus it can be concluded that nitrogen fixation is a minor source of nitrogen in the Potomac Estuary. Extension of recent data from studies at the University of Wisconsin [53] indicate that approximately 5,000 lbs/day of nitrogen could be fixed by blue-green algae in the upper and middle reaches of the Potomac Estuary. Nevertheless, compared to all other sources, the contribution from the atmosphere including that by nitrogen fixing algae appears to be insignificant. Thus, during the summer months, algal control by management of nitrogen appears to be a feasible alternative to phosphorus control.

Also in the above tabulation, the maximum percentage of carbon from wastewater is 35 percent. Other major sources not included in this figure are from the atmosphere, bacterial action in water, and bacterial action in the sediments. The quantity of carbon (CO_2) exchanged at the air-water interface is a function of the transfer rates, concentration of CO_2 in the air, pH of water, and the alkalinity of the water. For the Potomac, the maximum potential CO_2 transfer from the atmosphere is approximately 3,500,000,000 lbs/day*. This source from the atmosphere alone makes the possibility of effective carbon control doubtful at the present time since only about 100,000 lbs/day of carbon is discharged in wastewater with over 330,000 lbs/day from the upper basin.

---

* The CO_2 obtainable from the atmosphere was determined by using a transfer rate of 0.6 $mg/cm^2/min$ [32] for an upper estuary surface area equal to 2.0×10^9 ft^2.

Another aspect of nutrient management is the transport and/or deposit of the various nutrients along the longitudinal profile of the estuary. Because of the great solubility in water, inorganic nitrogen and carbon are easily transported through the estuary especially during high-flow periods in the winter and spring months.

The large quantities of phosphorus and organic carbon which originate in wastewater discharges do not move as easily through the estuary. Large quantities of phosphorus and organic carbon are lost to sediments. Analysis of the sediment confirms the deposit of both carbon and phosphorus (Figure VII-4).

A review of the management requirements for the estuarine reaches was made to determine if management of any single nutrient by wastewater treatment processes can achieve the water quality standards. For the lower and middle reaches, because of the large carbon supply intrusion from the Chesapeake Bay, the management of nitrogen and phosphorus appears to be a feasible approach. Management of the upper estuary is limited primarily to nitrogen and phosphorus control except during periods of extremely low flow when it is anticipated that the estuary will be used for a supplementary water supply. When the estuary is being so used, there will be little or no freshwater inflow thus the amount of inflow from the upper basin, especially carbon, is insignificant. Under these conditions, control of all three nutrients in the wastewater treatment process is feasible.

CARBON, TKN & PHOSPHORUS IN SEDIMENTS

POTOMAC ESTUARY
AUGUST 19-20, 1970

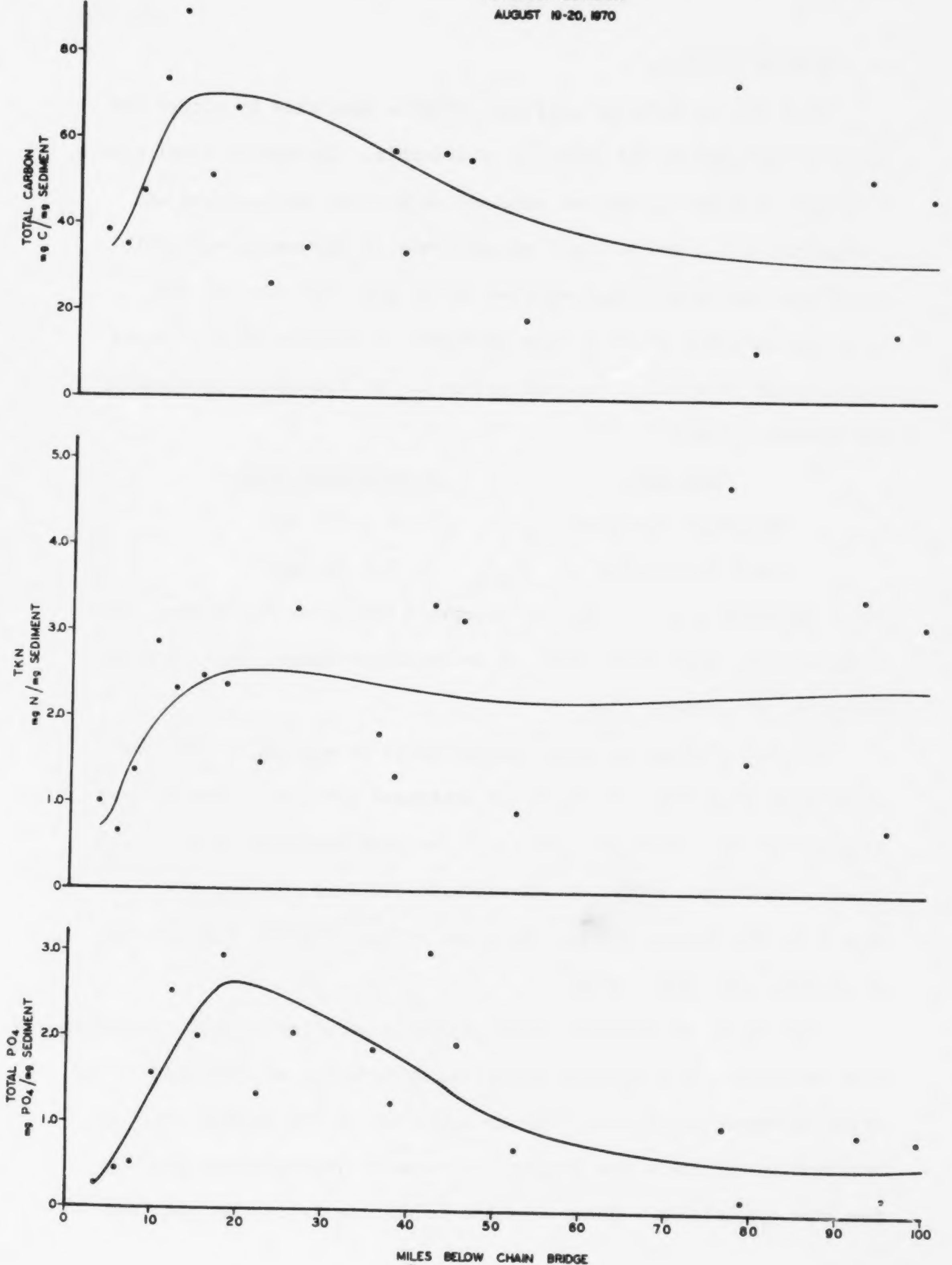


FIGURE VII-4

D. NUTRIENT CRITERIA

There are no existing nutrient criteria specified by either the State of Maryland or the District of Columbia. To control algal growth, the State of Virginia has set nutrient objectives for nitrogen and phosphorus of 1.0 and 0.2 mg/l respectively in wastewater effluent. Based upon the methodology reported in the previous section, the following nutrient criteria were developed in Section VII-B with the objective of reversal of eutrophication in the freshwater portions of the Potomac Estuary:

Parameter	Concentration Range
Inorganic Nitrogen	0.30 - 0.5 mg/l
Total Phosphorus	0.03 - 0.1 mg/l

Since there was over 5.0 mg/l of inorganic carbon in the estuary, even under maximum bloom conditions, no criteria for carbon could be established at the present time.

The lower values in these ranges are to be applied to the freshwater portion of Zone III and to the embayment portions of the estuary in which the environmental conditions are more favorable toward algal growth. The upper ranges of the criteria are more applicable to Zone I of the Potomac Estuary which has a light-limited euphotic zone of usually less than 2 feet.

Studies of the Potomac Estuary showed a relatively sharp transition from freshwater to a typical mesohaline environment as indicated by the rapid increase in salinity. At the upper end of the 22-mile reach at Maryland Point, there are primarily freshwater phytoplankton and zooplankton populations. Above Maryland Point, the salinities are less than two parts per thousand. At low flows, marine forms dominate the lower end of the transition zone at the Route 301 Bridge with salinities in summer approximating 12 parts per thousand.

Based on the past 5 years of field studies, it appears that the growth of massive blue-green algal mats are apparently restricted to the freshwater portions. In the mesohaline environment, dinoflagellates were often encountered in "red tide" proportions.

These observations lead to two points of emphasis in estuarine water quality management:

(1) Fairly discrete biotic provinces may be identified within a given reach of the estuary, responding differently to a given stress.

(2) There is insufficient evidence to date to generalize on nutrient parameters and hypertrophic conditions in all portions of a given estuary.

Therefore, at the present time, no specific nutrient criteria have been established for the mesohaline portion of the Potomac Estuary.

These criteria, along with a high degree of carbon removal for enhancement of dissolved oxygen would not only lead to a reversal of nutrient buildup in the estuary but also creation of an environment conducive to reversal of the aquatic plant succession that has occurred in the Potomac. This reversal has occurred in the lakes surrounding Madison, Wisconsin [17] and Lake Washington [16] when wastewater discharges were diverted from the lakes.

The criteria shown above give maximum concentrations for both nitrogen and phosphorus. Limits for both were incorporated for the following reasons:

(1) Since the flow of the Potomac River is very flashy, neither phosphorus nor nitrogen can be controlled throughout the estuary at all times. To reduce eutrophication in the entire estuary for years having average or above average flow conditions, phosphorus control appears to be more feasible. However, in the middle and upper estuary during low-flow years, nitrogen control appears to be more effective. This is because the nitrogen criterion for restricting algal growth is 10 times that for phosphorus (0.30 versus 0.03 mg/l) while the nitrogen loading from the wastewater treatment facilities is 2.4 times that of phosphorus (60,000 versus 24,000 lbs/day). Considering only the magnitude of the limiting nutrient concentrations and the magnitude of the percentage of the wastewater contribution, this results in more than a fourfold advantage in removing nitrogen over that of phosphorus.

(2) Various investigators report that increases in nitrogen and/or phosphorus can increase heterotrophic activity which in turn stimulates algal growth, and

(3) There is compatibility between wastewater treatment requirements for dissolved oxygen enhancement and eutrophication control.

Compatibility of treatment requirements is probably one of the most important considerations of the four factors influencing the selection of wastewater treatment unit processes. For example, to maintain the dissolved oxygen standard in the upper estuary under summer conditions, a high degree of carbonaceous and nitrogenous oxygen demand removal is required, whereas the control of algal standing crops is predicated on phosphorus and nitrogen removal. To obtain a high degree of carbonaceous oxygen demand removal, a chemical coagulation unit process is usually required beyond secondary treatment. This unit process will also remove a high percentage of phosphorus. The removal of the nitrogenous demand can be satisfied by one of two methods: (1) by converting the unoxidized nitrogen to nitrates (commonly called nitrification), or (2) by removal of nitrogen completely. If a unit process such as biological nitrification-denitrification is employed, both the DO and algal requirements for nitrogen can be met.

Thus with proper selection of wastewater treatment unit processes, it is feasible not only to enhance the DO by removing the carbonaceous and nitrogenous UOD but also to reduce nuisance algal growth by removing nutrients.

CHAPTER VIII

CONTROL CONSIDERATIONS FOR BACTERIAL DENSITIES, VIRUSES, HEAVY METALS, AND OTHER WATER QUALITY PARAMETERS

A. BACTERIAL DENSITIES

1. Indicator Organisms

Four bacterial organisms have been used as indicators of the sanitary water quality of the Potomac. These four are:

(1) Total coliform,

(2) Fecal coliform,

(3) Fecal streptococci, and

(4) Salmonella.

In a 1969 report entitled "Sanitary Bacteriology of the Upper Potomac Estuary" by Lear and Jaworski [33], the following conclusions were reached:

(1) High total coliform, fecal coliform, and fecal streptococci densities were found in the Washington metropolitan area,

(2) Fecal coliform/fecal streptococci ratios indicated that most of the bacterial pollution in the upper estuary was probably of human origin,

(3) A potential health hazard existed in the Washington area in that salmonella organisms were readily and regularly isolated in waters of the estuary, and

(4) In general, greater incidence of salmonella recovery occurred in waters having high total and/or fecal coliform densities.

Data collected during 1969 [34] also reflected the earlier findings including the salmonella isolations.

As reported earlier, all discharges from wastewater facilities in the upper estuary were being chlorinated as of September 1969. This has dramatically reduced fecal coliform densities near the wastewater outfalls. However, overflows from overloaded sanitary and combined sewers still cause high fecal coliform densities as was shown in Figure V-2. These high densities are a result of overflows of untreated wastewater entering the estuary near the confluence with Rock Creek.

The complete control of bacterial densities in the upper estuary cannot be realized until both continuous chlorination of wastewater effluent is maintained and sanitary, combined and storm sewer overflows are reduced or eliminated. While the storm sewers increase bacterial indicator densities in the estuary significantly, the increased flows tend to reduce their populations by dilution and to disperse them downstream. Apparently, the more persistent bacterial problems result from overflows of the combined sewer system, especially during the summer recreation period. This becomes increasingly serious when the estuary is considered as a public water supply source.

2. Bacterial Standards

The bacterial water quality standards for the upper estuary are as given below:

Jurisdiction	Total Coliform	Fecal Coliform
Virginia	2400 MPN/100 ml (monthly avg.)	200 MPN/100 ml (30-day log mean)
Maryland		240 MPN/100 ml (by survey)
District of Columbia		1000 MPN/100 ml (geometric mean)

For the shellfish producing area of the Potomac, a total coliform density of 70 MPN/100 ml is used by both the States of Maryland and Virginia.

B. VIRUSES

The role of water as a vector in the dissemination of viruses is not well understood. However, enteric viruses are present in sewage effluents and can find their ways into public water supplies [35].

In the Potomac Estuary, the problem of viruses and associated health hazards has three aspects that must be considered: (1) the lower portion of the estuary is a prime shellfish area, (2) the entire estuary is an ideal recreational use area, and (3) the upper estuary has been proposed as a public water supply source. While no epidemiological evidence exists relating waste discharges to the first two aspects presented, a potential hazard does exist at present and will probably become greater as the population increases.

The viral problem will be of major concern if the estuary is to be used as a water supply source. Since both wastewater effluents and overflows from storm, sanitary, and combined sewers contain viruses and do enter the estuary, the need to determine the threat to public health remains.

To evaluate this health hazard, a three-phase investigation is required to determine:

(1) The existing virus population along the longitudinal dimension of the estuary,

(2) The role of wastewater treatment facilities in removing viral particles, and

(3) The effectiveness of water treatment processes in removing viruses.

Studies regarding the viral removal effectiveness of wastewater and water supply treatment processes have been undertaken by FWQA's Advanced Waste Treatment Research Laboratory in Cincinnati, Ohio and by the U. S. Army Corps of Engineers, respectively. The FWQA studies include an investigation of the effect of advanced waste treatment processes on viruses. While a complete review is beyond the scope of this report, virus data on wastewater as reported by Berg [35] indicates that AWT units are approximately 90 percent effective in removing viruses. An evaluation of virus hazards by the American Society of Civil Engineers indicated that chlorination without reaching free chlorine residual will not insure virus free effluents [36].

As one aspect of the cooperative study with FWQA on the feasibility of the estuary as a supplemental water supply, the U. S. Army Corps of Engineers investigated the effectiveness of water supply treatment processes on virus removal. The study dealt primarily with the effectiveness of chlorination in deactivating various types of human enteric viruses.

A joint investigation by FWQA's Chesapeake Technical Support Laboratory and the Cincinnati Advanced Waste Treatment Research Laboratory to determine existing viral populations in the estuary was undertaken. Preliminary results from the first set of samples taken during the low-flow period of September 1970 for the stations presented below were negative.

Number	Station Location
I	Great Falls at Current Water Intake
II	Below Chain Bridge Near Site of Proposed Intake
III	Near Woodrow Wilson Bridge Below Blue Plains

This study is being continued and will be repeated under various temperature and flow conditions.

There are no water quality standards for viruses at present. Use of various indicator organisms such as coliforms have been suggested with the Bacillus subtilis spore [37] very promising as an indicator of virus disinfection.

A committee report for the American Water Works Association [38] summarized their study findings by stating: "There is no doubt that water can be treated so that it is always free from infectious microorganisms--it will be biologically safe. Adequate treatment means clarification (coagulation, sedimentation, and filtration), followed by effective disinfection." They further concluded that there is considerable room for research, both laboratory and epidemologic, to determine if there is a problem in virus disease transmission by water.

C. HEAVY METALS

A cooperative program with the laboratory at the U. S. Naval Ordnance Station in Indian Head, Maryland, to determine periodically the heavy metal occurrence in the Potomac Estuary waters and sediments was initiated during the summer of 1970. While only small concentrations of zinc and manganese were detected in the overlying waters of the estuary, considerable amounts of various heavy metals by acid extraction from the sediments were recorded.

From the sediment analysis (Table VIII-1), it can be seen that there are significant increases of lead, cobalt, chromium, cadmium, copper, nickel, zinc, silver, and barium in the upper estuary near the Woodrow Wilson Bridge. Since concentrations of metal are greatest near the sewage outfalls where other components of wastewater such as phosphorus and carbon are also highly concentrated, it can be concluded that the heavy metals originate in the wastewater discharges. Some accumulations such as cadmium could also be from urban and suburban runoff.

The effect of these heavy metal accumulations on the ecology of the estuary is indeterminate. Since the lower estuary is a prime shellfish production area, a study of the possible availability and effects of the apparently small but continuous discharges of heavy metals on the water quality and biota should be undertaken. With wastewater loadings projected to increase over fourfold and with increases in the number of discharge points farther down the estuary, this heavy metal accumulation could develop into a serious water quality management problem.

Heavy metals in the sediments must also be considered in the disposal of dredged spoil. Dredging operations involving deepening and widening of the channels near Washington, construction of piers and marinas, etc. disturb the sediments and require disposal of the dredged spoil. These activities should also be monitored especially where there are known high concentrations of potentially toxic metals in the sediments.

TABLE VIII-1

Heavy Metal Analyses of Sediment Samples August 18-20, 1970

Potomac Estuary

LOCATION	Pb ppm	Cd ppm	Co ppm	Cr ppm	Cu ppm	Mn ppm	Ni ppm	Zn ppm	Ca ppm	Mg ppm	K ppm	Fe %	Ag ppm	Li ppm	Ba ppm	V ppm	Al %	Sr ppm
Key Bridge	33.95	0.20	9.96	21.90	11.95	438.1	21.9	114.5	563	4047.2	49.8	1.792	0.6	10.0	54	⊖	0.946	6.2
14th Street Bridge	49.74	⊖	17.91	21.88	29.84	741.1	37.8	203.9	876	4829.5	129.3	2.736	1.4	15.1	96	30	1.343	9.4
Haines Point	61.88	0.60	19.96	37.93	33.93	823.4	37.9	244.5	878	4940.2	159.7	2.844	1.2	15.8	102	38	1.397	14.6
Bellevue	62.76	0.59	23.53	64.72	56.87	1029.6	43.1	318.7	495	4971.4	191.2	4.216	3.7	26.1	147	49	2.599	15.9
W. Wilson Bridge	85.83	0.40	25.95	75.85	61.88	1312.4	37.9	349.3	644	4945.0	119.8	4.241	6.4	23.0	178	42	2.096	14.2
Broad Creek	49.88	⊖	23.93	45.87	47.86	1740.0	37.9	269.2	1720	4826.2	99.7	3.739	3.2	17.8	114	36	1.645	10.0
Piscataway Creek	51.86	⊖	19.95	49.86	63.82	1645.5	47.9	279.2	439	4841.7	99.7	3.989	3.2	19.8	128	28	1.845	8.0
Dogue Creek	33.62	⊖	17.80	27.69	45.49	1473.1	19.8	222.5	406	4415.0	64.3	2.917	2.0	12.3	83	2	1.335	12.9
Hallowing Point	35.96	⊖	15.98	25.97	41.96	1353.6	22.0	219.8	400	4280.5	40.0	2.697	3.6	9.6	86	22	1.099	12.6
Indian Head	35.89	⊖	13.96	25.92	45.87	1580.4	18.0	239.3	489	4088.0	24.9	2.543	3.2	7.2	88	16	0.947	12.8
Possum Point	35.78	⊖	17.89	25.84	47.71	1709.7	23.9	258.4	393	4696.7	69.6	3.678	2.8	15.3	88	30	1.441	15.9
Sandy Point	35.71	⊖	17.85	31.74	47.61	2539.0	27.8	277.7	1949	4691.2	74.4	3.868	2.4	16.5	107	14	1.587	28.8
Smith Point	35.95	⊖	19.97	29.96	37.95	3225.6	36.0	244.7	170	4968.2	109.9	4.045	1.8	21.8	86	18	1.648	27.6
Maryland Point	42.66	⊖	19.39	29.08	50.41	2060.1	29.1	290.8	92	4798.9	116.3	4.217	2.1	21.5	66	19	1.697	19.0
Kettle Bottom Shoals	31.85	⊖	13.93	21.90	35.83	766.4	21.9	184.1	130	4811.5	189.1	3.185	1.0	18.7	26	18	1.543	18.5
Mouth of Wicomoco River	7.99	⊖	3.99	5.99	7.99	104.8	4.0	64.9	929	2026.6	15.0	0.899	1.4	5.0	10	⊖	0.749	10.4
Kingopisco River	19.88	⊖	7.95	15.91	25.85	457.3	19.9	208.8	948	4817.1	169.0	2.734	0.4	17.3	16	14	1.342	38.2
Ragged Point	19.80	⊖	9.90	15.84	39.59	623.6	25.7	183.1	248	4850.2	217.8	3.019	⊖	16.2	18	24	1.386	18.6
Piney Point	⊖	⊖	5.93	5.93	7.90	74.1	4.0	54.3	40	2404.8	19.8	0.741	⊖	3.4	4	10	0.790	1.6

⊖ = Concentration below detection limit.
Mo ppm, Se ppm, As ppm undetectable.

D. OTHER WATER QUALITY INDICATORS

Other water quality parameters are temperature, color, odor, taste, total dissolved solids, carbon chloroform extractions, pesticides, and herbicides.

1. Thermal

The most pronounced effect of thermal discharges on elevation of ambient water temperature can be found in the reach of the Potomac between Hains Point and Woodrow Wilson Bridge and in the Anacostia River near the Benning and East Capitol Street Bridges. Of these two areas, the rise in the Anacostia is the greatest with a 5-degree rise occurring above the ambient water temperature, reaching a high of 33°C.

Since the two areas periodically contain low dissolved oxygen concentrations, the effect of the elevated temperature is difficult to assess. Future thermal control may be required to provide a more favorable environment for aquatic life and to enhance dissolved oxygen when the wastewater plants are upgraded and the overflows from combined sewers are eliminated.

2. Carbon Chloroform Extraction

Using carbon chloroform extraction (CCE) as an indicator of potentially toxic organic materials, it can be seen in Figure VIII-1 that there is a significant increase in the waters between Great Falls and Memorial Bridge upstream from the combined sewer overflow discharges. At times, the relative increase is high, approximately 400 ug/l or 0.4 mg/l, twice the recommended standard for CCE.

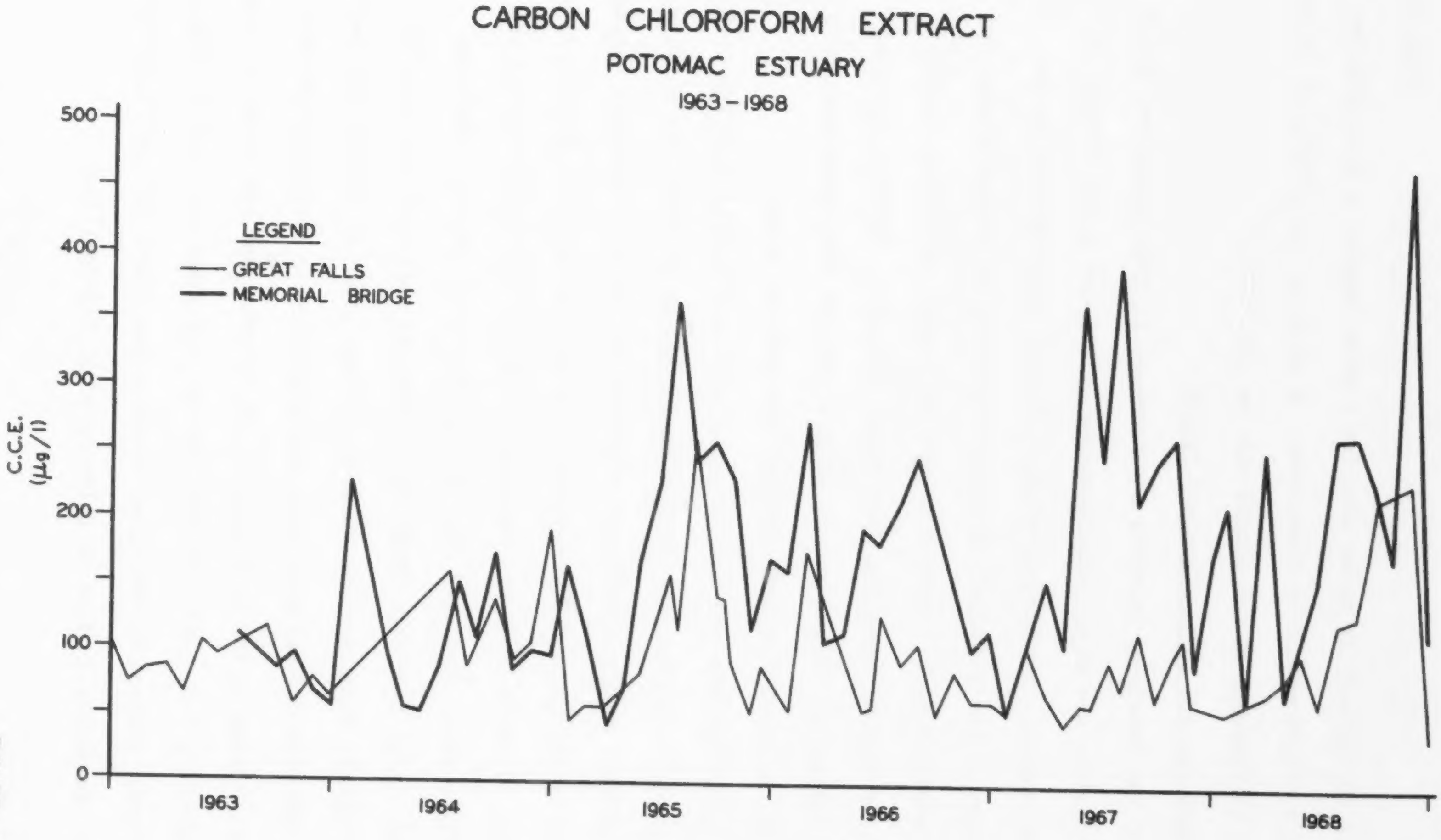


FIGURE VIII - 1

If the estuary is to be used for a water supply, a more detailed analysis of CCE should be undertaken. A study of the effects of water supply withdrawals on CCE should also be initiated.

3. Chlorides and Total Dissolved Solids

Of the remaining parameters, increases in total dissolved solids and chlorides are major considerations in the use of the estuary as a water supply. The concentrations of total dissolved solids and chlorides at the proposed intake are functions of concentrations in the freshwater flow, location of the salt wedge, and total increase of each parameter resulting from water treatment, domestic use, and waste treatment. Water quality simulations for both parameters were made using the FWQA Dynamic Estuary Mathematical Model.

To demonstrate the model's capability to simulate changing salinity conditions in the estuary, a test condition was selected for which sufficient data were available to establish the salinity gradient through the system at two different points in time. An historic period (July through December 1965) was selected for which flow conditions in the prototype were relatively uniform throughout the period. The mean Potomac River flow over Great Falls remained near 1300 cfs with the mean monthly flows varying between 1018 and 1586 cfs during this period.

Chloride and salinity data were available to establish the salt wedge position in the main stem of the Potomac near the start of this period (July 7-8, 1965) and near the end (December 1-2, 1965). These data were utilized to establish visually the "best fit" profiles for these two points in time as illustrated in Figure VIII-2.

The profile for July 7-8, 1965, was specified as the initial profile in the model. For the simulation, the network extended to Piney Point near River Mile 96. The specified chloride concentration at the seaward boundary was changed during the simulation in correspondence to the change noted in the prototype during the same period, i.e., the concentration was increased from 8400 mg/l to 10930 mg/l in small steps (increased 55 mg/l every 3 days). A uniform flow of 1300 cfs in the Potomac River was maintained throughout the simulation.

The chloride profile predicted by the mathematical model after the 147 day simulation period is also illustrated in Figure VIII-2 along with that measured in the estuary. The predicted and observed profiles, which overlap, indicate that the model can accurately simulate the intrusion of chloride from the Chesapeake Bay.

The simulation was completed utilizing a dispersion coefficient ranging from approximately 0.5 square miles per day (175 square feet per second) in the upper 55 miles of the estuary, 5.0 square miles per day (1600 ft^2/sec) in the next 15 miles, and 12.5 mi^2/day (4000 ft^2/sec) in the lower 26 miles of the estuary. These coefficients are of the order of magnitude suggested by Harleman [49] for the freshwater and salinity incursion zones, respectively, of estuary. These coefficients were utilized for the chloride and TDS simulations presented later in this report.

CHLORIDE CONCENTRATION

POTOMAC ESTUARY

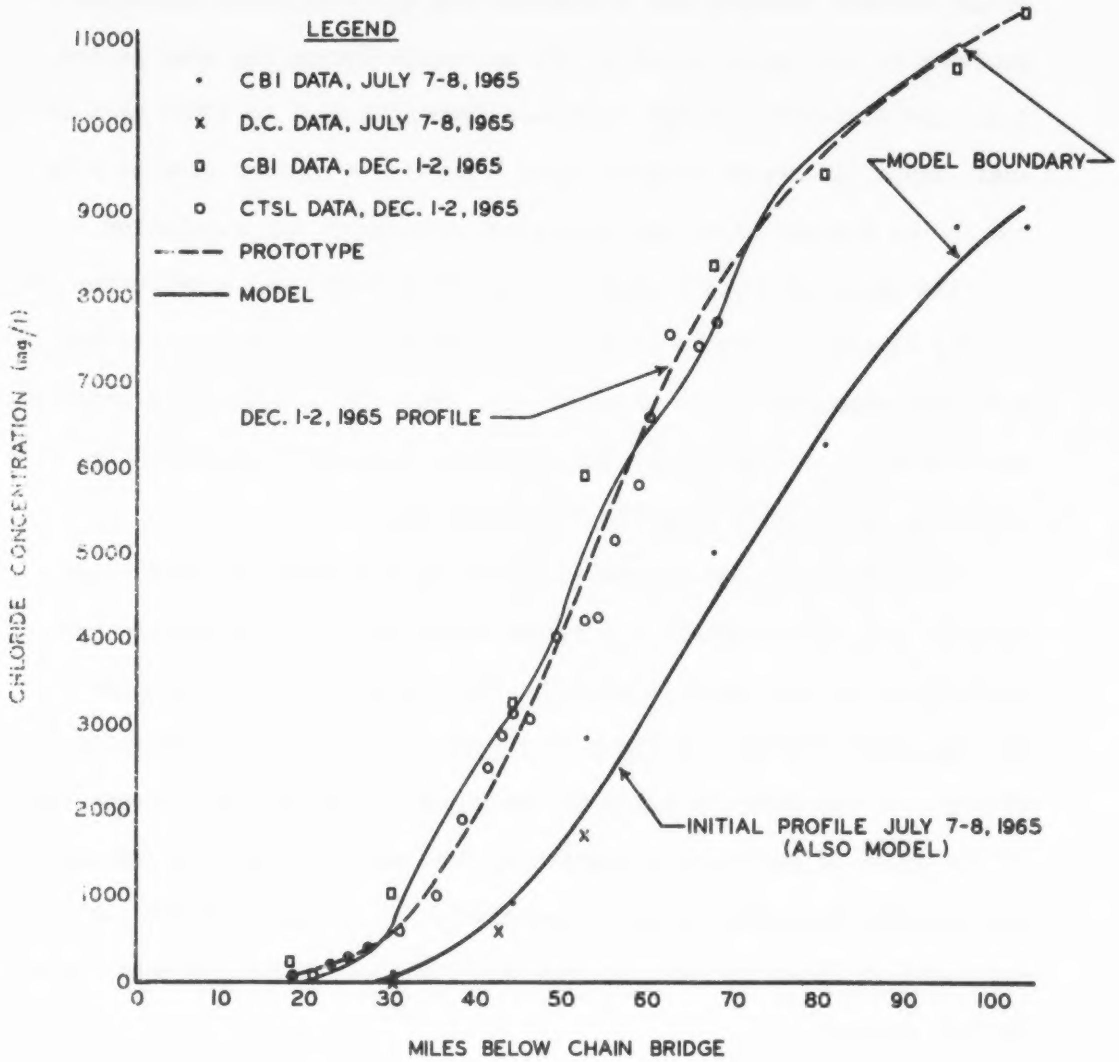


FIGURE VIII-2

4. Pesticides and Herbicides

Samples taken from six points in the Potomac Estuary were analyzed for 12 hydrocarbon pesticides in August 1969. None of these compounds were found at detectable concentrations in the samples nor in a 24-hour composite sample taken from the Blue Plains Sewage Treatment Plant effluent [34]. Since there is considerable agricultural use of pesticides and herbicides within the Potomac River Basin at certain times of the year, further EPA surveys to include those seasons of use are indicated as well as a data search of investigations by other agencies.

CHAPTER IX

POPULATION AND WASTEWATER PROJECTIONS

A. POPULATION PROJECTIONS

To facilitate the determination of wastewater loading rates and water supply requirements for the entire Washington metropolitan area, population projections were developed for 13 service areas. Delineation of watersheds within each service area is presented in Table IX-1.

Population data for the Virginia and Maryland portions of the Washington metropolitan area along with the District of Columbia are shown in Figure IX-2 for the three benchmarks investigated. Summarized below are the total population projections for the Washington metropolitan area:

Year	Population
1969	2,800,000
1980	4,000,000
2000	6,700,000
2020	9,300,000

Population projections for the benchmark years of 1980 and 2000 were furnished by the Metropolitan Washington Council of Governments (COG). Control populations for these benchmarks were based on the "low-estimate" figures prepared for COG by Hammer, Green, Siler Associates [39]. Distribution by individual service areas was essentially determined from 1960-1968 population trends with consideration

Table IX-1
DATA SUMMARY
FACILITY SERVICE AREAS

Number	Service Area	State	Watersheds
I	Upper Potomac	Virginia	Goose Creek, Broad Run, Sugarland Run, Nichols Run, Ponds Branch, Mine Run, Mine Run, Difficult Run
II	Upper Potomac	Maryland	Upper County, Seneca Creek, Muddy Branch, Cabin John, Rock Run
III	Rock Creek	Maryland	Rock Creek
IV	Pentagon	Virginia	Pentagon
V	Anacostia Valley	Maryland	Anacostia River
VI	Arlington	Virginia	Arlington (Pimmit and Four Mile Runs)
VII	District of Columbia	-	District of Columbia, Oxon Run
VIII	Alexandria	Virginia	Alexandria
VIII-A	Cameron Run and Belle Haven	Virginia	Cameron Run and Belle Haven
IX	Piscataway	Maryland	Piscataway Creek, Swan Creek, Henson Creek, Andrews Air Force Base
X	Lower Potomac	Virginia	Accotink Creek, Pohick Creek, Dogue Creek, Little Hunting Creek, Fort Belvoir
XI	Mattawoman	Maryland	Mattawoman Creek (Prince George's County), Mattawoman Creek (Charles County), Indian Head Naval Station
XII	Occoquan	Virginia	Lorton, Occoquan Tributaries (Fairfax County), Occoquan Tributaries (Prince William County), Marumsco Creek, Neabsco Creek, Powell Creek, Quantico Creek, Quantico Marine Base

given to land use potential and other attenuating factors. A similar methodology was employed by FWQA's Middle Atlantic Region economists to develop population estimates for the year 2020 benchmark except that the control figure was derived from a long-term relationship of national, regional, and metropolitan area population trends.

WASTEWATER SERVICE AREAS
WASHINGTON METROPOLITAN AREA

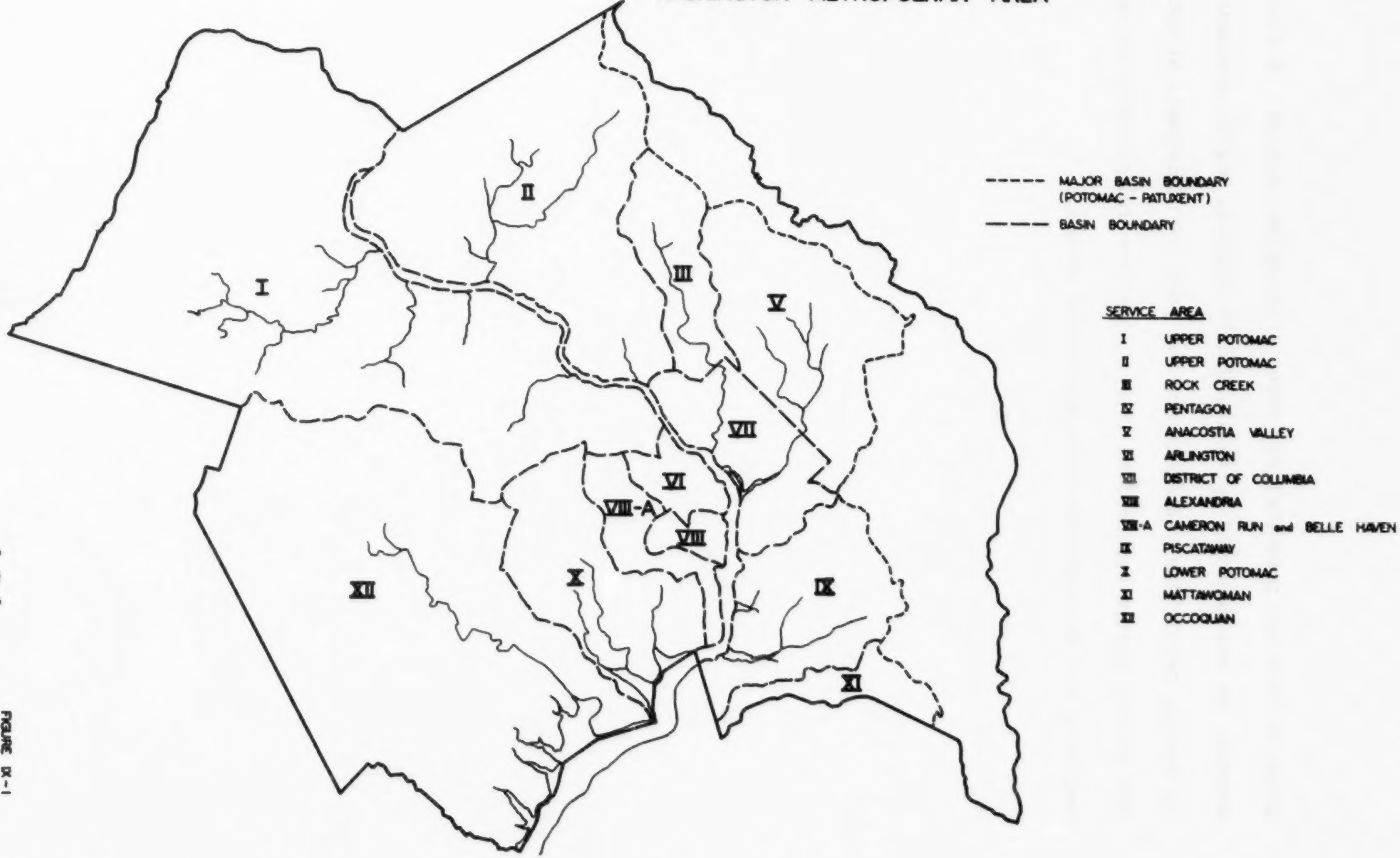

I
II
III
V
VI
VII
VIII-A
VIII
IX
X
XI
XII
MAJOR BASIN BOUNDARY (POTOMAC - PATUXENT)
BASIN BOUNDARY
SERVICE AREA
I UPPER POTOMAC
II UPPER POTOMAC
III ROCK CREEK
IV PENTAGON
V ANACOSTIA VALLEY
VI ARLINGTON
VII DISTRICT OF COLUMBIA
VIII ALEXANDRIA
VIII-A CAMERON RUN and BELLE HAVEN
IX PISCATAWAY
X LOWER POTOMAC
XI MATTAWOMAN
XII OCCOQUAN

FIGURE IX-1

POPULATION PROJECTIONS

WASHINGTON METROPOLITAN AREA

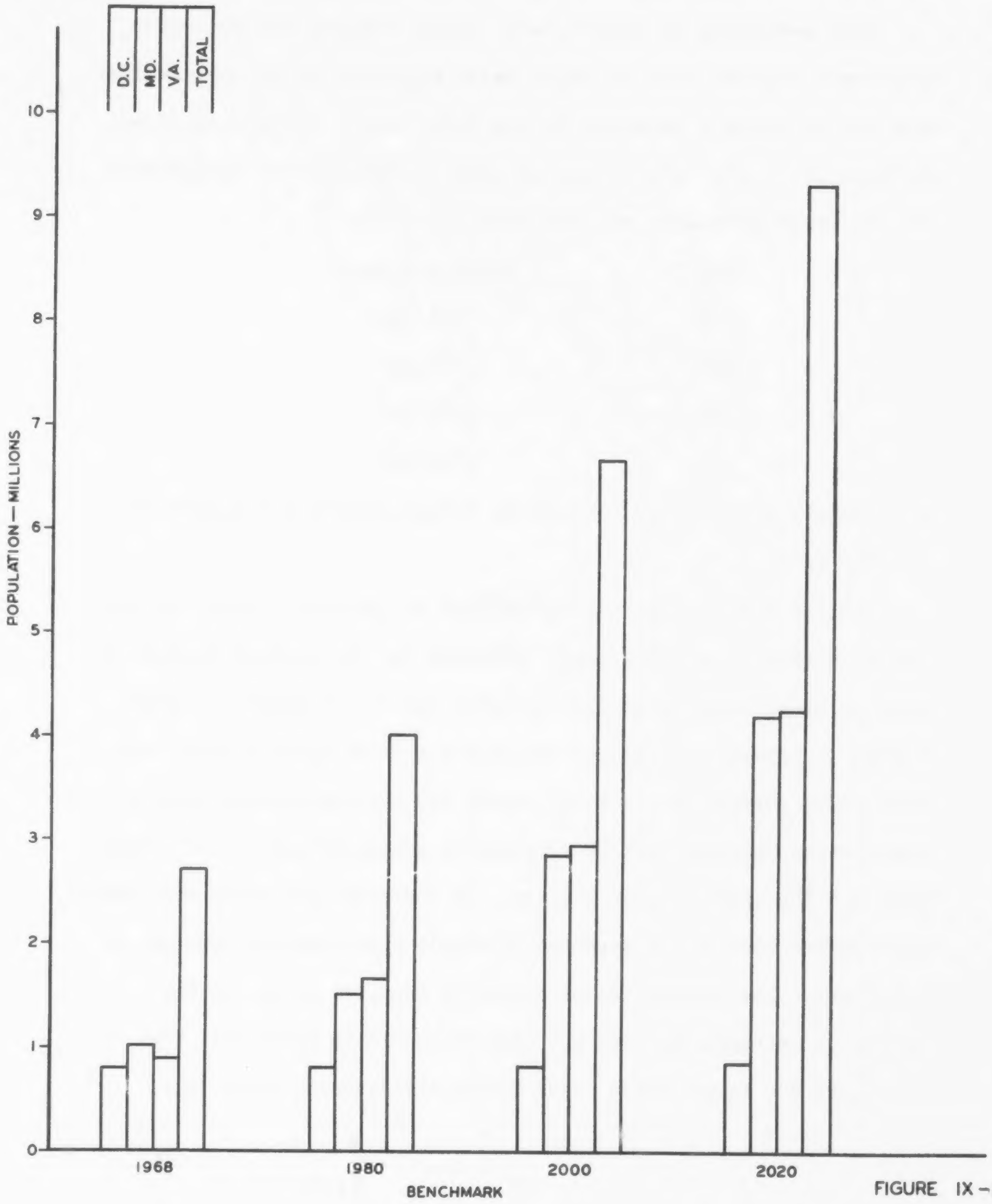


FIGURE IX-2

B. WATER SUPPLY REQUIREMENTS

Data pertaining to current water supply demands and per capita usage were obtained from the major water suppliers in the metropolitan area and served as a baseline for the water supply projections shown in Table IX-2. The total projected average yearly water requirements for the three benchmarks are presented as follows:

Year	Projected Usage
1969	370 mgd
1980	556 mgd
2000	1009 mgd
2020	1568 mgd

Water supply requirements for shorter demand periods are delineated in Table IX-3.

The per capita water use was assumed to increase through the year 2020 at a rate of one gpcd/year. Allowing for the maximum dependable yield of other existing sources of water such as Occoquan and Goose Creeks, it appears that all of the District of Columbia's water supply and a major portion of the water supply for the metropolitan area within Virginia and Maryland must be provided by a combination of the Potomac River and the upper Potomac Estuary. Of the total projected 2020 demand, these latter sources are expected to supply approximately 1400 mgd or 90 percent. The Patuxent River currently supplies 42 mgd to the Washington metropolitan area but will be unable to serve this area in the future due to projected needs within the Patuxent Basin [40].

Table IX-2

WATER SUPPLY REQUIREMENTS
WASHINGTON METROPOLITAN AREA

	Present (1969)			1980			2000			2020		
	Population Served	Total Water Usage (mgd)	Per Capita Water Usage (gpd)	Population Served	Per Capita Water Usage (gpd)	Total Water Usage (mgd)	Population Served	Per Capita Water Usage (gpd)	Total Water Usage (mgd)	Population Served	Per Capita Water Usage (gpd)	Total Water Usage (mgd)
District of Columbia	800,000	161.00	200	823,800	210	173.00	843,700	230	194.00	855,000	250	214.00
Maryland	1,100,000	131.00	120	1,534,000	130	199.00	2,863,300	150	430.00	4,201,700	170	714.00
Virginia	800,000	78.00	100	1,674,600	110	184.00	2,963,000	130	385.00	4,268,900	150	640.00
Totals	2,700,000	370.00		4,032,400		556.00	6,670,000		1009.00	9,325,600		1568.00

Table IX-3

VARIOUS WATER SUPPLY DEMANDS
Washington Metropolitan Area

Duration	1980 (mgd)	2000 (mgd)	2020 (mgd)
Maximum Day	1,001	1,816	2,822
Maximum Five Day	950	1,730	2,680
Maximum Month	723	1,312	2,038
Maximum Two Months	712	1,292	2,007
Maximum Three Months	695	1,261	1,960
Maximum Six Months	634	1,150	1,788
Yearly Average	556	1,009	1,568

C. WASTEWATER LOADINGS

Utilizing the population projections discussed previously and the current waste flows and loading rates for each existing treatment facility as shown in Table IX-4, future wastewater trends were developed for the 13 service areas comprising the Washington metropolitan area. These data are presented in Tables IX-5, IX-6, and IX-7 for 1980, 2000, and 2020 respectively. It can be seen from these tables that the BOD, nitrogen and phosphorus loadings before treatment are projected to increase drastically. The table below summarizes these loading conditions:

Year	Flow	Before Treatment BOD_5 (lbs/day)	TKN as N (lbs/day)	T. P as P (lbs/day)
1969	325	483,500	63,500	27,300
1980	473	823,500	95,600	43,100
2000	861	1,463,500	155,700	70,300
2020	1342	2,195,000	215,600	97,400

Wastewater flows were adjusted upward to reflect the additional per capita water usage. Consumptive losses were maintained at approximately 14 percent. In the case of Federal installations, waste flow was computed by assuming a per capita contribution of 100 gpd. The per capita BOD load was also increased slightly in accordance with historical loading trends while current per capita nitrogen and phosphorus loadings were held constant for each of the benchmark years.

Table IX-4

PRESENT WASTEWATER LOADINGS
WASHINGTON METROPOLITAN AREA

Facility	Average Waste Flow (mgd)	Population Served	Per Capita Waste Flow (gpd)	Untreated BOD_5 (lbs/day)	Per Capita BOD_5 Load (lbs/day)	Untreated TKN as N (lbs/day)	Per Capita TKN Load (lbs/day)	Untreated TPO_4 as PO_4 (lbs/day)	Per Capita TPO_4 Load (lbs/day)
Pentagon	1.060	10,600*	100	2,100	0.20	440	0.042	182	0.017
Arlington	19.390	247,000	79	33,500	0.14	4,800	0.019	4,575	0.018
Sewer Overflows-D. C.	2.516	18,300**	138	3,740	0.20	460	0.025	645	0.035
U. S. Naval Laboratory	0.095	950*	100	25	0.03	30	0.030	30	0.030
District of Columbia	251.660	1,830,000	138	373,700	0.20	46,000	0.025	64,539	0.035
Alexandria	23.300	190,000	123	38,000	0.20	4,580	0.024	6,060	0.031
Fairfax-Westgate	11.570	124,400	93	11,500	0.09	3,140	0.025	3,394	0.027
Piscataway	5.810	55,000	106	6,300	0.11	1,650	0.030	1,106	0.020
Andrews AFB No. 1	0.820	8,200*	100	1,200	0.15	70	0.008	152	0.018
Andrews AFB No. 4	0.086	860*	100	104	0.12	12	0.014	18	0.021
Naval Comm. Station	0.067	670*	100	110	0.16	15	0.020	15	0.020
Fairfax-Hunting Creek	3.260	25,000	130	4,060	0.16	720	0.029	833	0.033
Fairfax-Dogue Creek	2.441	20,000	122	4,048	0.20	465	0.023	606	0.030
Fort Belvoir No. 1	0.600	3,600	167	1,100	0.30	145	0.040	76	0.021
Fort Belvoir No. 2	2.340	18,400	127	3,500	0.19	960	0.052	394	0.021
Fairfax-Lower Potomac***	-	-	-	-	-	-	-	-	-
Naval Ordnance Station Indian Head									
Site I	0.250	2,500*	100	155	0.06	30	0.012	50	0.020
Site II	0.360	3,600*	100	355	0.10	10	0.003	30	0.008
Site III	0.006	60*	100	2	0.03	2	0.033	5	0.083
Site IV	0.001	10*	100	2	0.20	2	0.200	5	0.500
TOTALS	325.630	2,559,150		483,501		63,531		82,715	

* Based on 100 gpcpd
** Based on dry weather flow to wastewater facility
*** Under construction

Table IX-5

1980 WASTEWATER LOADINGS
WASHINGTON METROPOLITAN AREA

Facility	Population Served	Per Capita Waste Flow (gpd)	Average Waste Flow (mgd)	Per Capita BOD$_5$ Load (lbs/day)	Untreated BOD$_5$ (lbs/day)	Per Capita TKN Load (lbs/day)	Untreated TKN (lbs/day)	Per Capita TPO$_4$ Load (lbs/day)	Untreated TPO$_4$ (lbs/day)
Upper Potomac, Va.	231,340	110	25.45	0.22	50,895	0.025	5,784	0.035	8,097
Upper Potomac, Md.	241,818	110	26.60	0.22	53,200	0.025	6,045	0.035	8,464
Rock Creek, Md.	232,548	110	25.58	0.22	51,161	0.025	5,814	0.035	8,139
Pentagon, Va.	10,600	100	1.06	0.22	2,332	0.042	445	0.017	180
Anacostia Valley, Md.	614,295	110	67.57	0.22	135,145	0.025	15,357	0.035	21,500
Arlington, Va.	228,000	100	22.80	0.20	45,600	0.020	4,560	0.030	6,840
District of Columbia	823,818	170	140.05	0.22	181,240	0.025	20,595	0.035	28,834
Alexandria, Va.	155,300	130	20.19	0.22	34,166	0.025	3,883	0.035	5,436
Cameron Run & Bell Haven, Va.	163,100	110	17.94	0.22	35,882	0.025	4,078	0.035	5,709
Piscataway, Md.	191,000	120	22.92	0.17	32,470	0.030	5,730	0.030	5,730
Lower Potomac, Va.	423,933	110	46.63	0.22	93,265	0.025	10,598	0.035	14,838
Mattawoman, Md.	35,032	110	3.85	0.22	7,707	0.025	876	0.035	1,226
Occoquan, Va.	411,966	110	45.32	0.22	90,633	0.025	10,299	0.035	14,419
Sewer Overflows, D. C.	10,588	170	1.80	0.22	2,329	0.025	265	0.035	371
U. S. Naval Laboratory	1,000	100	0.10	0.05	50	0.030	30	0.030	30
Andrews AFB No. 1	9,000	100	0.90	0.17	1,530	0.010	90	0.020	180
Andrews AFB No. 4	1,000	100	0.10	0.14	140	0.016	16	0.023	23
Naval Communications Station	700	100	0.07	0.18	126	0.020	14	0.020	14
Fort Belvoir No. 1	4,200	167	0.70	0.30	1,260	0.040	168	0.020	84
Fort Belvoir No. 2	18,900	127	2.40	0.20	3,780	0.050	945	0.020	378
Naval Ordnance Station Indian Head									
Site I	3,000	100	0.30	0.06	180	0.012	36	0.020	60
Site II	4,000	100	0.40	0.10	400	0.003	12	0.008	32
Site III	100	100	0.01	0.03	3	0.033	3	0.083	8
Site IV	10	100	-	0.20	2	0.200	2	0.500	5
TOTALS	3,815,248		472.74		823,496		95,645		130,597

Table IX-6

2000 WASTEWATER LOADINGS
WASHINGTON METROPOLITAN AREA

Facility	Population Served	Per Capita Waste Flow (gpd)	Average Waste Flow (mgd)	Per Capita BOD_5 Load (lbs/day)	Untreated BOD_5 (lbs/day)	Per Capita TKN Load (lbs/day)	Untreated TKN (lbs/day)	Per Capita TPO_4 Load (lbs/day)	Untreated TPO_4 (lbs/day)
Upper Potomac, Va.	412,596	130	53.64	0.24	99,023	0.025	10,315	0.035	14,441
Upper Potomac, Md.	700,000	130	91.00	0.24	168,000	0.025	17,500	0.035	24,500
Rock Creek, Md.	319,959	130	41.59	0.24	76,790	0.025	7,999	0.035	11,199
Pentagon, Va.	10,600	100	1.06	0.24	2,544	0.042	445	0.017	180
Anacostia Valley, Md.	971,175	130	126.25	0.24	233,082	0.025	24,279	0.035	33,991
Arlington, Va.	309,000	120	37.08	0.22	67,980	0.020	6,180	0.030	9,270
District of Columbia	843,724	190	160.31	0.24	202,494	0.025	21,093	0.035	29,530
Alexandria, Va.	199,900	150	29.99	0.24	47,976	0.025	4,998	0.035	6,997
Cameron Run& Belle Haven, Va.	241,800	130	31.43	0.24	58,032	0.025	6,045	0.035	8,463
Piscataway, Md.	340,000	140	47.60	0.19	64,600	0.030	10,200	0.030	10,200
Lower Potomac, Va.	769,347	130	100.02	0.24	184,643	0.025	19,234	0.035	26,927
Mattawoman, Md.	66,140	130	8.60	0.24	15,874	0.025	1,654	0.035	2,315
Port Tobacco, Md.	47,000	130	6.11	0.24	11,280	0.025	1,175	0.035	1,645
Occoquan, Va.	930,355	130	120.95	0.24	223,285	0.025	23,259	0.035	32,562
Sewer Overflows, D. C.	1,842	190	0.35	0.24	442	0.025	46	0.035	64
U. S. Naval Laboratory	1,000	100	0.10	0.05	50	0.030	30	0.030	30
Andrews AFB No. 1	9,000	100	0.90	0.17	1,530	0.010	90	0.020	180
Andrews AFB No. 4	1,000	100	0.10	0.14	140	0.016	16	0.023	23
Naval Communications Station	700	100	0.07	0.18	126	0.020	14	0.020	14
Fort Belvoir No. 1	4,200	167	0.70	0.30	1,260	0.040	168	0.020	84
Fort Belvoir No. 2	18,900	127	2.40	0.20	3,780	0.050	945	0.020	378
Naval Ordnance Station Indian Head									
Site I	3,000	100	0.30	0.06	180	0.012	36	0.020	60
Site II	4,000	100	0.40	0.10	400	0.003	12	0.008	32
Site III	100	100	0.01	0.03	3	0.033	3	0.083	8
Site IV	10	100	-	0.20	2	0.200	2	0.500	5
TOTALS	6,205,348		860.96		1,463,516		155,738		213,098

Table IX-7

2020 WASTEWATER LOADINGS
WASHINGTON METROPOLITAN AREA

Facility	Population Served	Per Capita Waste Flow (gpd)	Average Waste Flow (mgd)	Per Capita BOD_5 Load (lbs/day)	Untreated BOD_5 (lbs/day)	Per Capita TKN Load (lbs/day)	Untreated TKN (lbs/day)	Per Capita TPO_4 Load (lbs/day)	Untreated TPO_4 (lbs/day)
Upper Potomac, Va.	588,600	150	88.29	0.26	153,036	0.025	14,715	0.035	20,601
Upper Potomac, Md.	1,328,600	150	199.29	0.26	345,436	0.025	33,215	0.035	46,501
Rock Creek, Md.	341,100	150	51.17	0.26	88,686	0.025	8,528	0.035	11,939
Pentagon, Va.	10,600	100	1.06	0.26	2,756	0.042	445	0.017	180
Anacostia Valley, Md.	1,233,400	150	185.00	0.26	320,684	0.025	30,835	0.035	43,169
Arlington, Va.	320,400	140	44.86	0.24	76,896	0.020	6,408	0.030	9,612
District of Columbia	855,000	210	179.55	0.26	222,300	0.025	21,375	0.035	29,925
Alexandria, Va.	236,200	170	40.15	0.26	61,412	0.025	5,905	0.035	8,267
Cameron Run & Belle Haven, Va.	284,800	150	42.72	0.26	74,048	0.025	7,120	0.035	9,968
Piscataway, Md.	485,100	160	77.62	0.21	101,871	0.030	14,553	0.030	14,553
Lower Potomac, Va.	1,115,000	150	167.25	0.26	289,900	0.025	27,875	0.035	39,025
Mattawoman, Md.	89,100	150	13.37	0.26	23,166	0.025	2,228	0.035	3,119
Port Tobacco, Md.	75,000	150	11.25	0.26	19,500	0.025	1,875	0.035	2,625
Occoquan, Va.	1,567,900	150	235.19	0.26	407,654	0.025	39,198	0.035	54,877
Sewer Overflows, D. C.	714	210	0.15	0.26	186	0.025	18	0.035	25
U. S. Naval Laboratory	1,000	100	0.10	0.05	50	0.030	30	0.030	30
Andrews AFB No. 1	9,000	100	0.90	0.17	1,530	0.010	90	0.020	180
Andrews AFB No. 4	1,000	100	0.10	0.14	140	0.016	16	0.023	23
Naval Communications Station	700	100	0.07	0.18	126	0.020	14	0.020	14
Fort Belvoir No. 1	4,200	167	0.70	0.30	1,260	0.040	168	0.020	84
Fort Belvoir No. 2	18,900	127	2.40	0.20	3,780	0.050	945	0.020	378
Naval Ordnance Station Indian Head									
Site I	3,000	100	0.30	0.06	180	0.012	36	0.020	60
Site II	4,000	100	0.40	0.10	400	0.003	12	0.008	32
Site III	100	100	0.01	0.03	3	0.033	3	0.083	8
Site IV	10	100	-	0.20	2	0.200	2	0.500	5
TOTALS	8,573,424		1341.90		2,195,002		215,609		295,200

CHAPTER X

WATER QUALITY SIMULATIONS

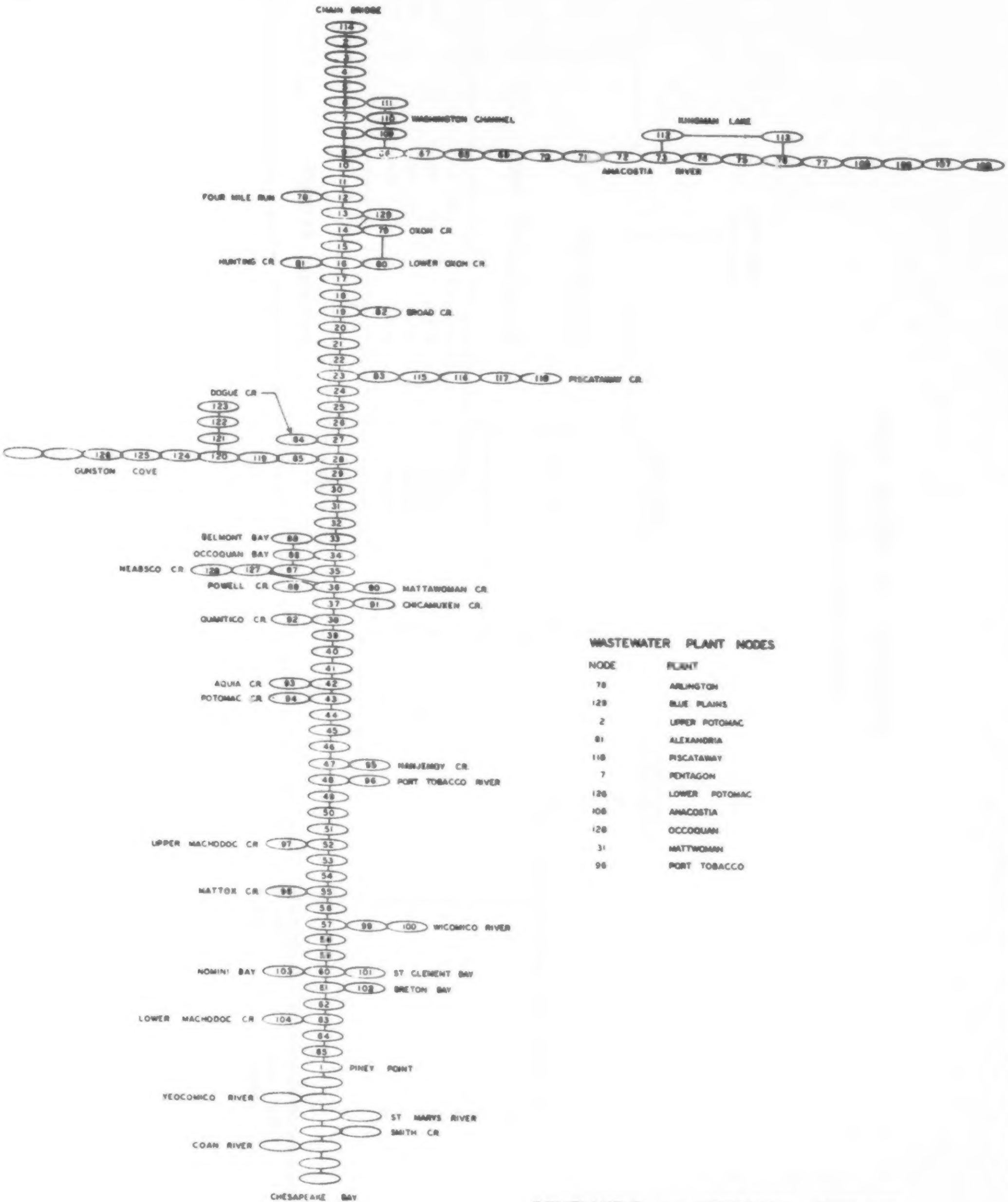
A. WATER QUALITY SIMULATION MODELS

Water quality simulations for this report were made using the FWQA Dynamic Estuary Model (DEM) and DECS III. The DEM, which was used to evaluate allowable wastewater loadings and chloride intrusion as discussed subsequently in this chapter, is a real-time system incorporating a hydraulic component that describes tidal movement and a quality component that considers the basic transport mechanisms of advection and dispersion as well as the pertinent sources and sinks of each constituent. The ability to utilize a two-dimensional network of interconnecting junctions and channels makes it possible to include the embayments directly in the flow network. A detailed description of the model is available from FWQA [41]. DECS III is based on a time-dependent tidal average solution of the basic mass balance equations as originally developed by Thomann [54]. This model was used to investigate seasonal variations in the nitrogen and phosphorus distributions of the upper Potomac Estuary.

A study investigating the relative merits of the FWQA Dynamic Estuary Model versus the tidal average approach has been made by CTSL and a report of this investigation is currently in preparation.

A schematic diagram of the Potomac Estuary used in the Dynamic Estuary Model is given in Figure X-1. The location nodes for the existing discharges and proposed locations for future discharges are also shown in this figure. A similar segmentation of the main Potomac was also used for DECS III.

In simulating the various water quality constitutents, a water flow system as shown in Figure X-2 was incorporated into the Dynamic Estuary Model. This feature was necessary to simulate conservative constituents such as chlorides and total dissolved solids.


CHAIN BRIDGE
WASHINGTON CHANNEL
KINGMAN LAKE
ANACOSTIA RIVER
FOUR MILE RUN
OXON CR
HUNTING CR
LOWER OXON CR
BROAD CR
PISCATAWAY CR
DOGUE CR
GUNSTON COVE
BELMONT BAY
OCCOQUAN BAY
NEABSCO CR
POWELL CR
MATTAWOMAN CR
CHICAMUXEN CR
QUANTICO CR
AQUIA CR
POTOMAC CR
NANJEMOY CR
PORT TOBACCO RIVER
UPPER MACHODOC CR
MATTOX CR
WICOMICO RIVER
NOMINI BAY
ST CLEMENT BAY
BRETON BAY
LOWER MACHODOC CR
PINEY POINT
YEOCOMICO RIVER
ST MARYS RIVER
SMITH CR
COAN RIVER
CHESAPEAKE BAY

WASTEWATER PLANT NODES

NODE	PLANT
78	ARLINGTON
129	BLUE PLAINS
2	UPPER POTOMAC
81	ALEXANDRIA
118	PISCATAWAY
7	PENTAGON
126	LOWER POTOMAC
108	ANACOSTIA
128	OCCOQUAN
31	MATTWOMAN
96	PORT TOBACCO

SCHEMATIC OF POTOMAC ESTUARY
FOR FWQA DYNAMIC MODEL

FIGURE X-1

SCHEMATIC OF WATER FLOW

WATER QUALITY SIMULATION

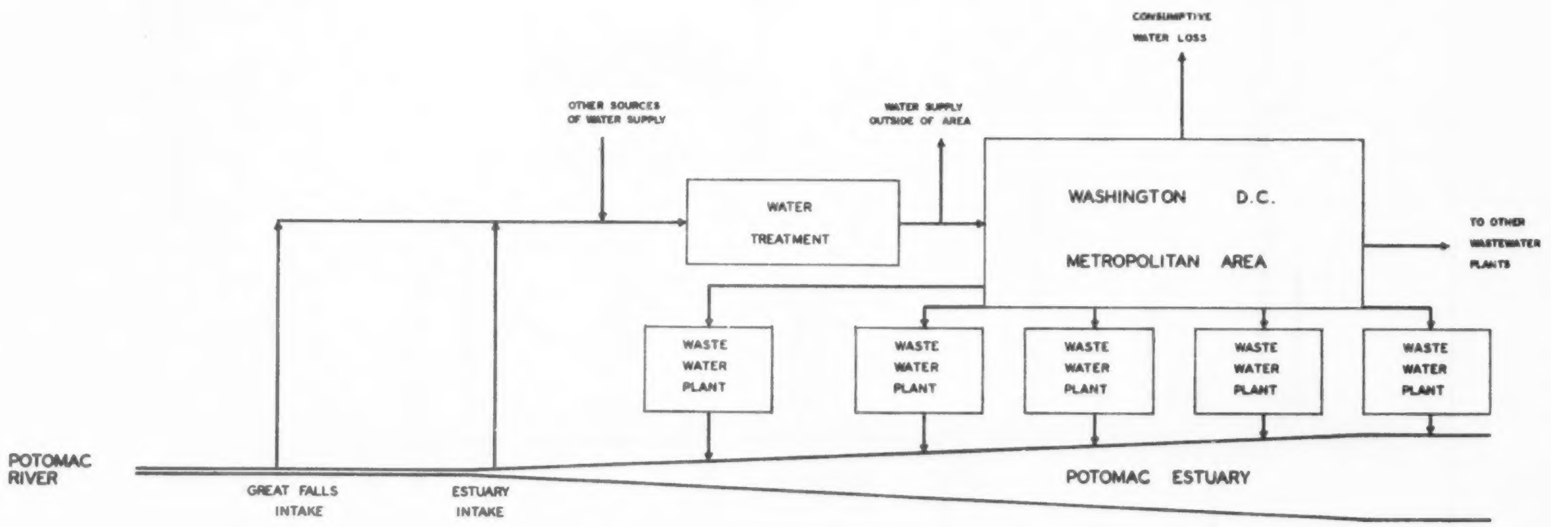

CONSUMPTIVE WATER LOSS
OTHER SOURCES OF WATER SUPPLY
WATER SUPPLY OUTSIDE OF AREA
WATER TREATMENT
WASHINGTON D.C. METROPOLITAN AREA
TO OTHER WASTEWATER PLANTS
WASTE WATER PLANT
WASTE WATER PLANT
WASTE WATER PLANT
WASTE WATER PLANT
WASTE WATER PLANT
POTOMAC RIVER
GREAT FALLS INTAKE
ESTUARY INTAKE
POTOMAC ESTUARY

FIGURE X-2

B. ALTERNATIVE WASTEWATER TREATMENT SYSTEMS

As shown in Figures X-3, X-4, and X-5, three basic alternative wastewater treatment systems were investigated. A fourth system, similar to Alternative III except for a facility on Rock Creek, was also investigated; however, the population projections indicated that the expanded Blue Plains, Upper Potomac, and Anacostia plants could readily serve the Rock Creek area and this alternative was subsequently omitted. Alternative discharge locations for two of the above schemes were considered in the mathematical model simulation and are presented in Figures X-6 and X-7.

Alternative I consisted of nine wastewater treatment plants in the upper Potomac Estuary. The projected waste flows for each of these facilities are shown in the following table:

Table X-1
WASTEWATER FACILITIES AND PROJECTED FLOWS
Alternative I

Facility	1980 (mgd)	2000 (mgd)	2020 (mgd)
Pentagon	1	1	1
Arlington	23	37	45
Blue Plains	285*	473	702
Alexandria	38	61	83
Piscataway	24	49	79
Lower Potomac	50	103	170
Occoquan	45	121	235
Mattawoman	5	9	13
Port Tobacco	0	6	11

* Proposed capacity = 309 mgd

WASTEWATER TREATMENT SYSTEMS
UPPER POTOMAC ESTUARY
ALTERNATIVE I

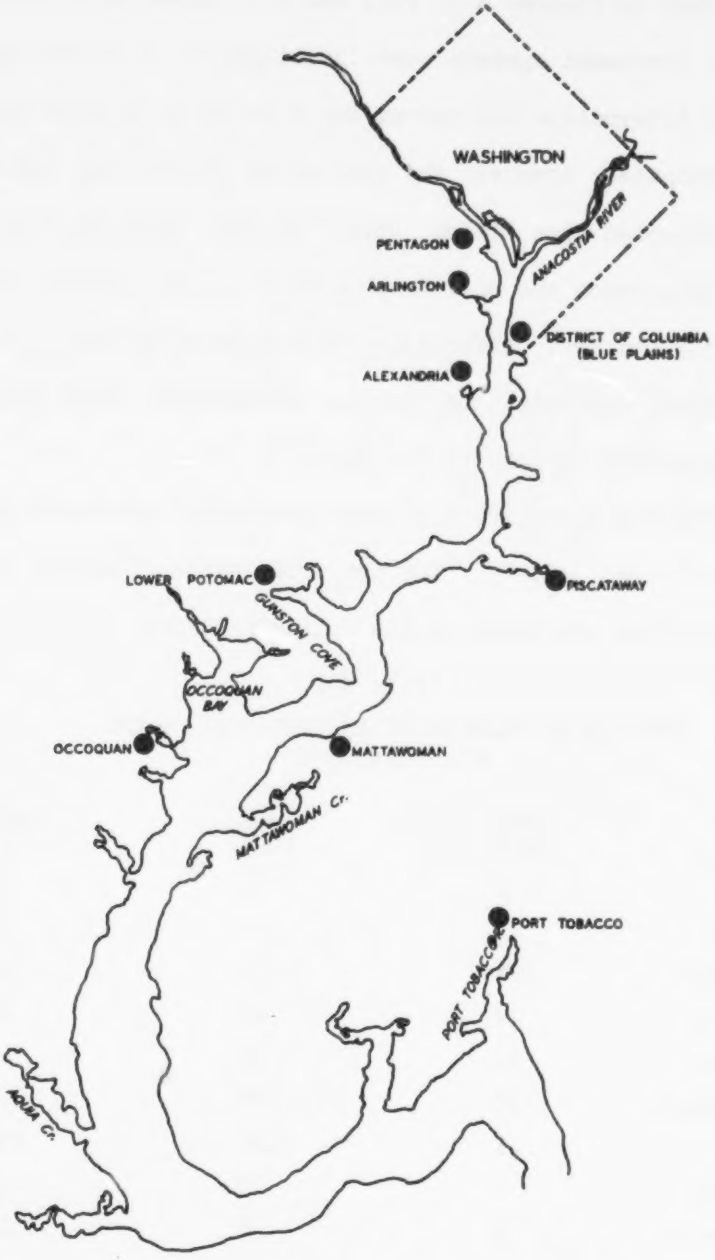

WASHINGTON
PENTAGON
ARLINGTON
ANACOSTIA RIVER
DISTRICT OF COLUMBIA
(BLUE PLAINS)
ALEXANDRIA
PISCATAWAY
LOWER POTOMAC
GUNSTON COVE
OCCOQUAN BAY
OCCOQUAN
MATTAWOMAN
MATTAWOMAN Cr.
PORT TOBACCO
PORT TOBACCO R.
AQUIA Cr.

FIGURE X-3

WASTEWATER TREATMENT SYSTEMS

UPPER POTOMAC ESTUARY

ALTERNATIVE II

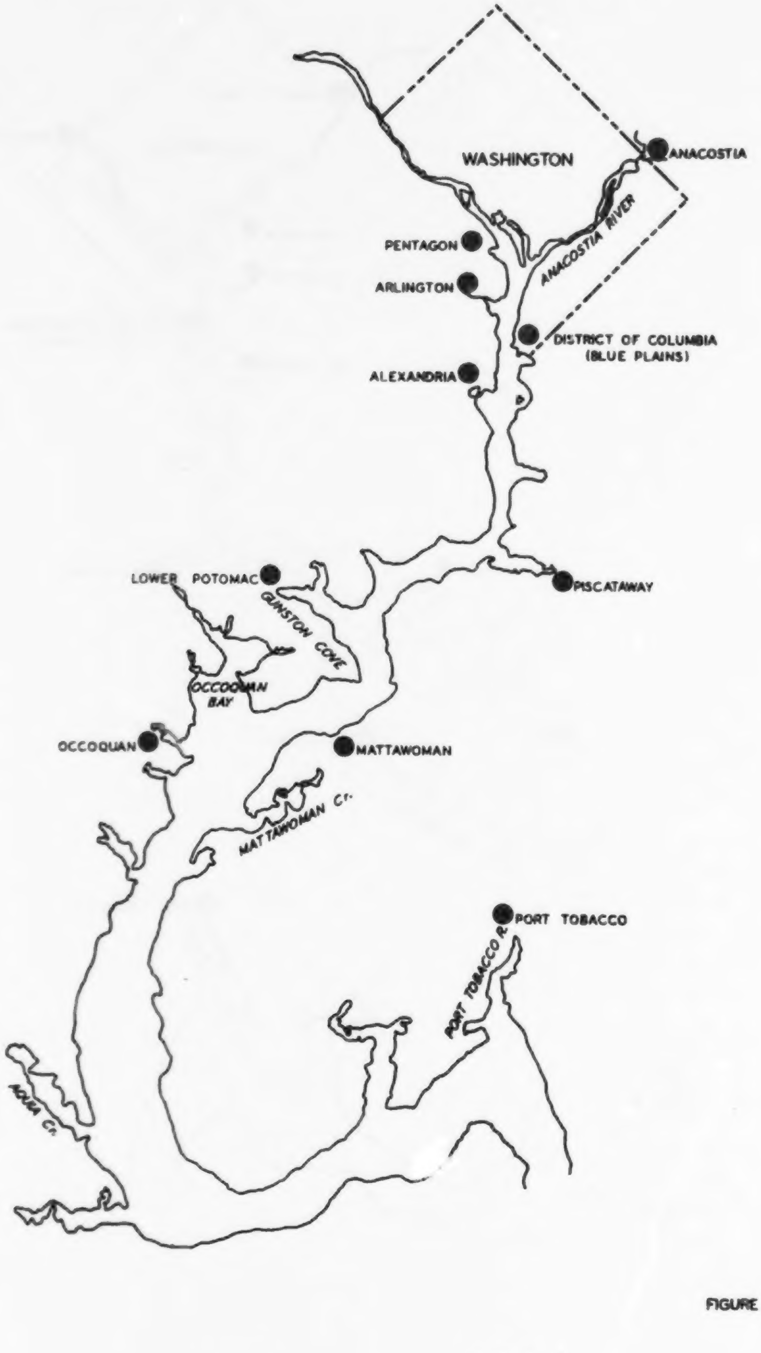

WASHINGTON
ANACOSTIA
ANACOSTIA RIVER
PENTAGON
ARLINGTON
DISTRICT OF COLUMBIA
(BLUE PLAINS)
ALEXANDRIA
LOWER POTOMAC
GUNSTON COVE
PISCATAWAY
OCCOQUAN BAY
OCCOQUAN
MATTAWOMAN
MATTAWOMAN Cr.
PORT TOBACCO
PORT TOBACCO R.
AQUIA Cr.

FIGURE X-4

WASTEWATER TREATMENT SYSTEMS

UPPER POTOMAC ESTUARY

ALTERNATIVE III

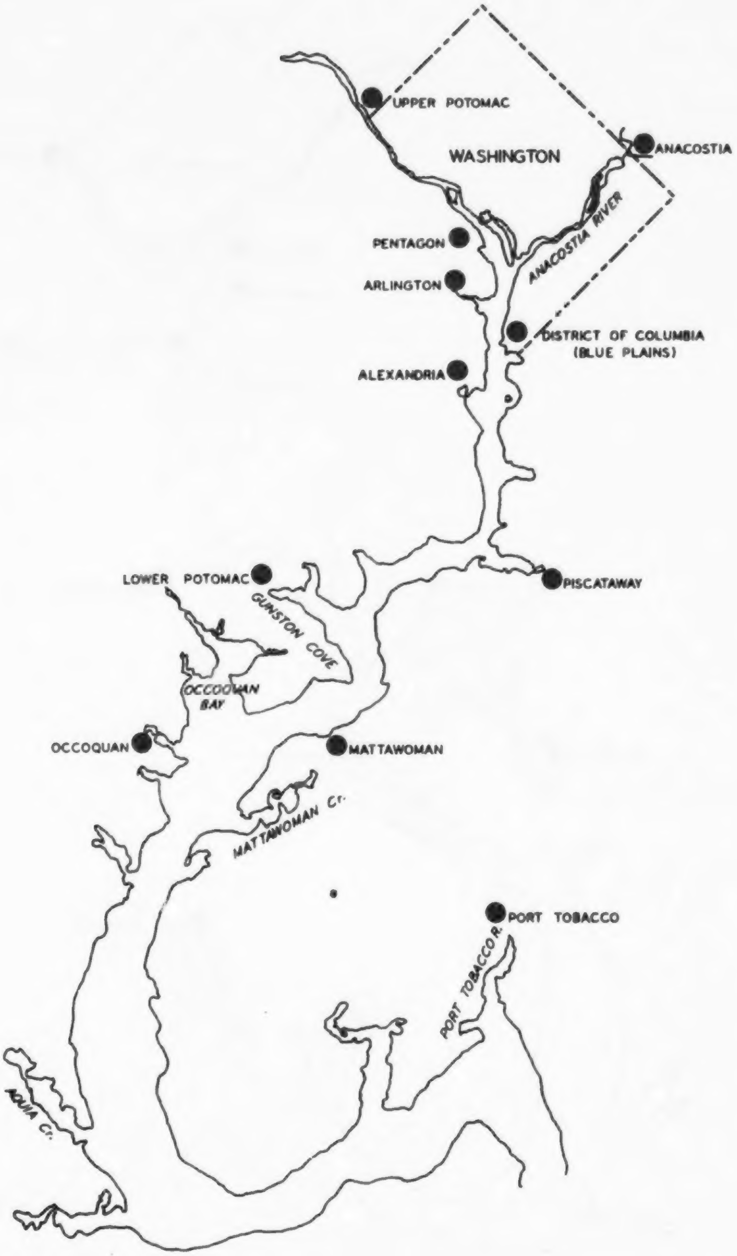

UPPER POTOMAC
WASHINGTON
ANACOSTIA
ANACOSTIA RIVER
PENTAGON
ARLINGTON
DISTRICT OF COLUMBIA (BLUE PLAINS)
ALEXANDRIA
LOWER POTOMAC
GUNSTON COVE
PISCATAWAY
OCCOQUAN BAY
OCCOQUAN
MATTAWOMAN
MATTAWOMAN Cr.
PORT TOBACCO
PORT TOBACCO R.
AQUIA Cr.

FIGURE X-5

WASTEWATER TREATMENT SYSTEMS

UPPER POTOMAC ESTUARY

ALTERNATIVE IV

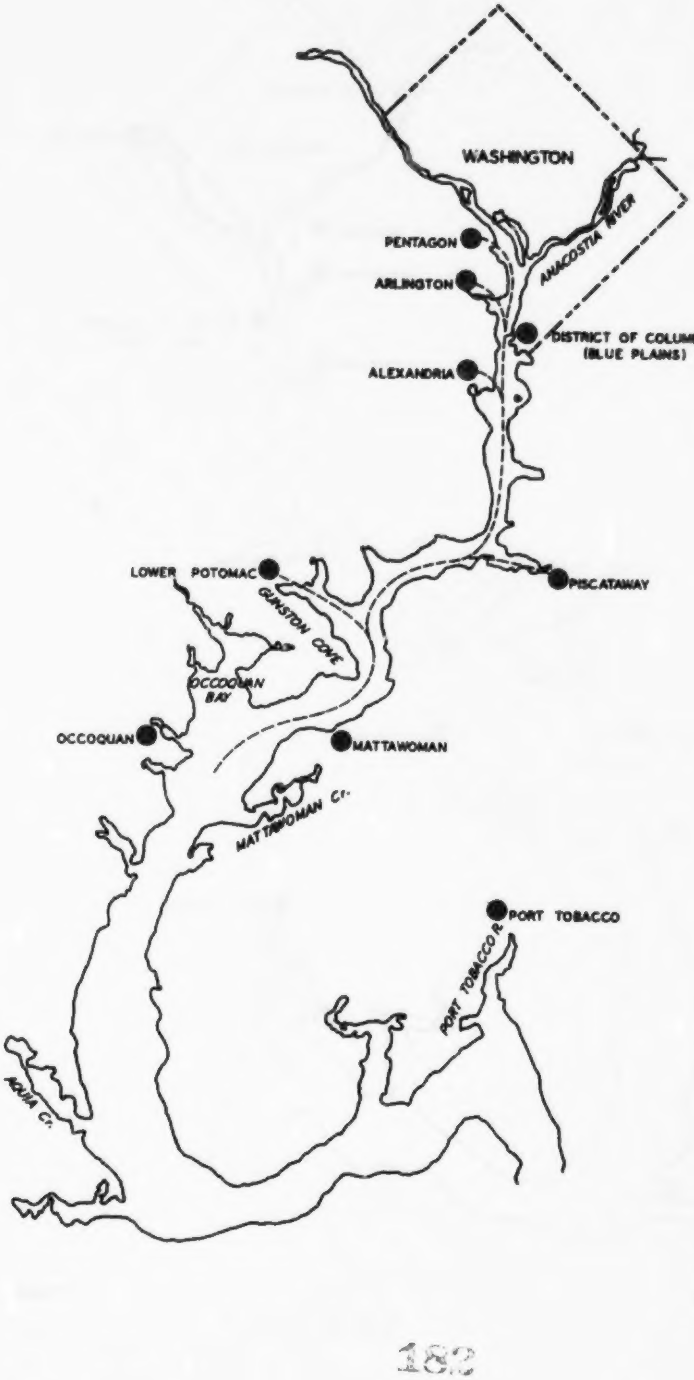
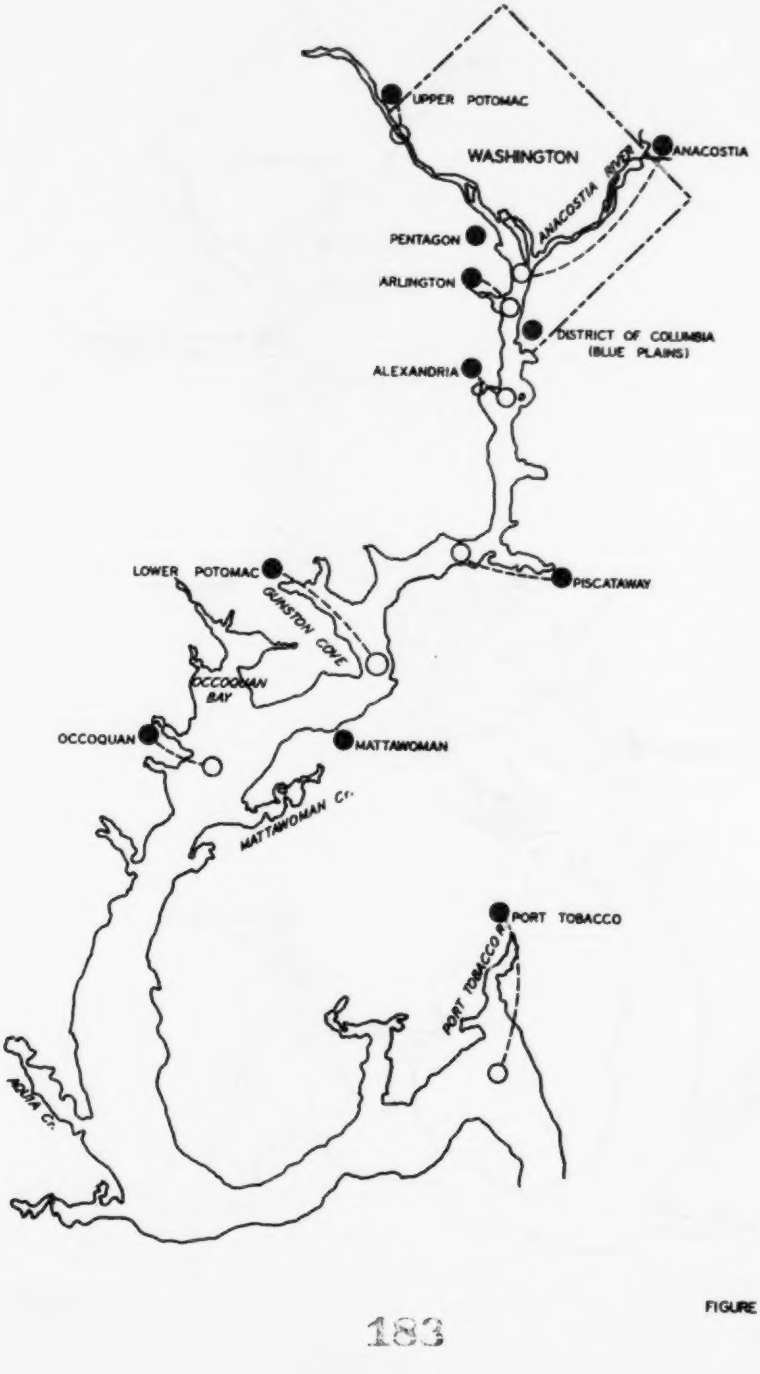

WASHINGTON
PENTAGON
ARLINGTON
ANACOSTIA RIVER
DISTRICT OF COLUMBIA
(BLUE PLAINS)
ALEXANDRIA
LOWER POTOMAC
GUNSTON COVE
PISCATAWAY
OCCOQUAN BAY
OCCOQUAN
MATTAWOMAN
MATTAWOMAN Cr.
PORT TOBACCO
PORT TOBACCO R.
AQUIA Cr.

FIGURE X-6

WASTEWATER TREATMENT SYSTEMS

UPPER POTOMAC ESTUARY

ALTERNATIVE V



UPPER POTOMAC
WASHINGTON
ANACOSTIA
ANACOSTIA RIVER
PENTAGON
ARLINGTON
DISTRICT OF COLUMBIA (BLUE PLAINS)
ALEXANDRIA
LOWER POTOMAC
GUNSTON COVE
PISCATAWAY
OCCOQUAN BAY
OCCOQUAN
MATTAWOMAN
MATTAWOMAN Cr.
PORT TOBACCO
PORT TOBACCO R.
AQUIA Cr.

FIGURE X-7

Under Alternative I, the District of Columbia's Blue Plains facility will also serve the upper Potomac area within Virginia and Maryland, the Anacostia Valley, and the Rock Creek Basin. In this alternative, it is assumed that the expansion at Blue Plains is not restricted. In all three alternatives, Alexandria's facility will also serve the Cameron Run and Belle Haven areas, Piscataway will serve Andrews Air Force Base, and the Lower Potomac plant will serve Fort Belvoir. The existing Fairfax Dogue and Little Hunting Creek plants are to be abandoned and the waste transported to the Lower Potomac facility.

Alternative II was identical to Alternative I except that a wastewater plant was assumed on the Anacostia River. This facility will only serve the Anacostia Valley. It was also assumed that the Blue Plains treatment plant would be expanded to accomodate the remainder of the flow. The facilities and wastewater flows associated with Alternative II are shown in Table X-2.

Table X-3 shows wastewater facility data corresponding to Alternative III which assumes another plant built in 1980 to serve the upper Potomac area. In Alternative III, the maximum size of Blue Plains is limited to 309 mgd. The Anacostia facility would serve the Anacostia Valley and the remainder of the flow shown as transported to Blue Plains in the first two alternatives would be conveyed to the upper Potomac plant.

Table X-2

WASTEWATER FACILITIES AND PROJECTED FLOWS
Alternative II

Facility	1980 (mgd)	2000 (mgd)	2020 (mgd)
Pentagon	1	1	1
Arlington	23	37	45
Anacostia	0	126	185
Blue Plains	285*	347	518
Alexandria	38	61	83
Piscataway	24	49	79
Lower Potomac	50	103	170
Occoquan	45	121	235
Mattawoman	5	10	13
Port Tobacco	0	6	11

* Proposed capacity = 309 mgd

Table X-3

WASTEWATER FACILITIES AND PROJECTED FLOWS
Alternative III

Facility	1980 (mgd)	2000 (mgd)	2020 (mgd)
Pentagon	1	1	1
Upper Potomac	0	38	209
Anacostia	0	126	185
Arlington	23	37	45
Blue Plains	285*	309	309
Alexandria	38	61	83
Piscataway	24	49	79
Lower Potomac	50	103	170
Occoquan	45	121	235
Mattawoman	5	10	13
Port Tobacco	0	6	11

* Proposed capacity = 309 mgd

Alternative III is similar to the proposals in the "Memorandum of Understanding" with reference to the Washington metropolitan regional water pollution control plan as presented at a special session of the Potomac River Washington Metropolitan Area Enforcement Conference on October 13, 1970. In this memorandum, a maximum capacity of 309 mgd for the Blue Plains facility was proposed. It also required the appropriate parties to provide another regional plant or plants to accomodate the projected increases in wastewater volumes.

While there can be numerous variations of Alternative III in respect to flow distribution, the basic layout concept is fundamental. Alternative V, presented later in this report, is one variation with discharge points to the main Potomac.

Alternative IV, which is identical with Alternative I for wastewater treatment plant location, differs in that the effluents from the upper six plants are conveyed downstream as far as Occoquan Bay. This plan was investigated to determine the effects of discharges lower in the estuary on its use as a water supply source (Figure X-6).

Alternative V was developed to investigate the effects of discharging the effluents directly into the main Potomac instead of the embayments. This alternative, which is identical to Alternative III in facility locations has the Anacostia, Arlington, Alexandria, Piscataway, Lower Potomac, Occoquan, and Port Tobacco facilities discharging into the Potomac main channel. The Blue Plains, Upper Potomac, and Mattawoman facilities either do or were assumed to discharge into the main channel.

The estuary water supply intake was assumed to be one-half mile below Chain Bridge. In Figure X-1, the schematic diagram for the model, the water supply intake is at Node 114.

When the current wastewater collection and treatment facilities, projected populations, "Memorandum of Understanding," and water supply needs are reviewed, it can readily be observed that:

(1) Shortly after 1980, the Dulles Interceptor with its current capacity of 64 mgd will be overloaded.

(2) To provide for future wastewater collection and treatment services in the upper Potomac, either the Dulles Interceptor should be significantly enlarged or wastewater treatment facilities constructed in this region.

(3) If the Dulles Interceptor is enlarged, wastewater treatment capacity must be increased at either Blue Plains, Anacostia Valley, and Piscataway or a combination of all three.

(4) With the current capacity limitation of 309 mgd at Blue Plains, it appears that treatment facilities will be needed not only in the upper Potomac but also in the Anacostia Valley.

(5) Large wastewater volumes will be generated in the lower counties of Virginia, mainly in the Occoquan and Pohick watersheds.

The above five observations indicate that consideration in selection of wastewater management programs should not only include treatment facilities but also collection systems. This is discussed in greater detail later in this report when the water supply aspects are presented.

C. WASTEWATER MANAGEMENT ZONES AND STREAMFLOW CRITERIA

To facilitate determination of wastewater management requirements, the upper and middle estuary were initially divided into three 15-mile zones with similar physical characteristics beginning at Chain Bridge. This allowed greater flexibility in developing control needs.

River mile distances for the three upper zones, from both the Chesapeake Bay and Chain Bridge, are given in Table X-4. The zonal concept was adopted by the Conferees at the Potomac Enforcement Conference Progress Meeting on May 8, 1969.

More recent studies have suggested that Zone I be divided into three subzones as shown in Figure X-8. The three subzones are described as follows:

Subzone	Description
I-a	Potomac Estuary from Chain Bridge to Hains Point, a distance of 7.6 miles
I-b	Anacostia tidal river from Bladensburg, Maryland to the confluence with the Potomac, a distance of 9.0 miles
I-c	Potomac Estuary from Hains Point to Broad Creek, a distance of 7.4 miles

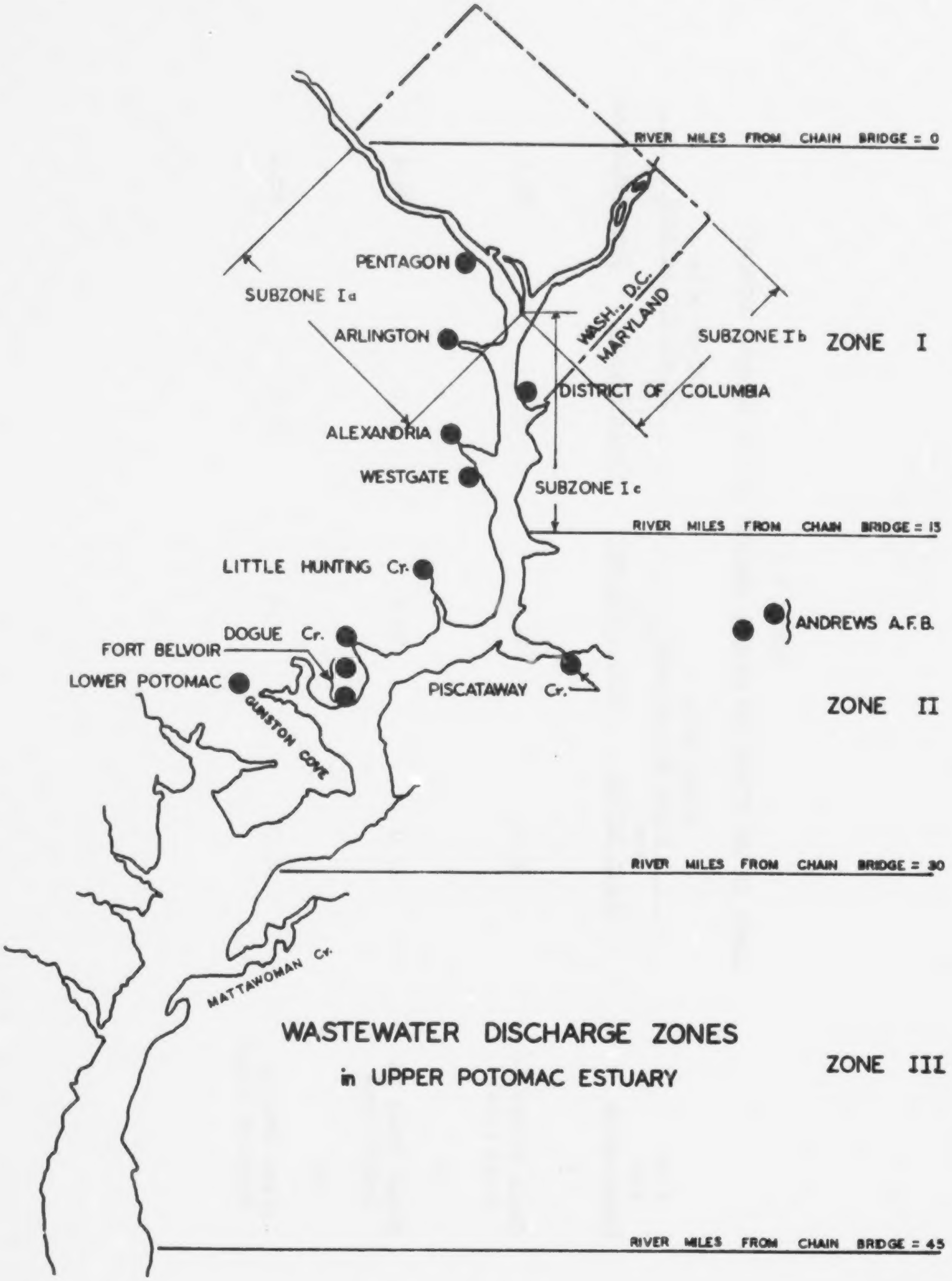
Discharges to embayments are also considered in this report.

Using the zonal concept, a total maximum loading for a specific pollutant is given for each zone. Allocation of pound loading for each discharge can be obtained by prorating the total zonal poundage using various bases such as population, drainage areas, and geographical subdivisions.

Table X-4

ZONES OF THE UPPER AND MIDDLE REACHES OF THE POTOMAC ESTUARY

Zone and Description	River Mile Upper End of Zone		River Mile Lower End of Zone	
	from Chain Bridge	from Chesapeake Bay	from Chain Bridge	from Chesapeake Bay
I				
Chain Bridge to Broad Creek	0.0	114.4	15.0	99.4
II				
Broad Creek to Indian Head	15.0	99.4	30.0	84.4
III				
Indian Head to Maryland Point	30.0	84.4	45.0	69.4



WASTEWATER DISCHARGE ZONES in UPPER POTOMAC ESTUARY

RIVER MILES FROM CHAIN BRIDGE = 0
PENTAGON
SUBZONE Ia
ARLINGTON
WASH., D.C.
MARYLAND
SUBZONE Ib
ZONE I
DISTRICT OF COLUMBIA
ALEXANDRIA
WESTGATE
SUBZONE Ic
RIVER MILES FROM CHAIN BRIDGE = 15
LITTLE HUNTING Cr.
ANDREWS A.F.B.
DOGUE Cr.
FORT BELVOIR
LOWER POTOMAC
GUNSTON COVE
PISCATAWAY Cr.
ZONE II
RIVER MILES FROM CHAIN BRIDGE = 30
MATTAWOMAN Cr.
ZONE III
RIVER MILES FROM CHAIN BRIDGE = 45

FIGURE X-8

The 7-day-low-flow into the Potomac Estuary, with a recurrence interval of once-in-10-years, is 954 cfs before water supply diversion. Since the need for water supply is projected to utilize all of the river flow during critical flow conditions by 1980, a design flow of 300 cfs was used in determining wastewater loadings. This minimum flow serves to maintain an ecological balance in critical stream segments during low-flow periods as well as preserve the aesthetic appearance of this historic area. Where applicable, effects of flow changes including withdrawal from the estuary for water supply are also presented.

D. ULTIMATE OXYGEN DEMAND

The interrelationship between ultimate oxygen demand* (UOD) and dissolved oxygen (DO) in the Potomac Estuary was determined using a verified mathematical model. Studies included investigations of alternative wastewater treatment schemes, UOD loading rates, and net flows into the estuary for the three benchmark years. Maximum allowable UOD loadings in pounds per day, based upon compliance with existing DO stream standards were established for each of the zones including the embayments.

In developing the allowable UOD loadings, the reaction kinetics, as given in Chapter VI, were used, including the following DO criteria:

Parameter	Value
Water temperature	29.0°C
DO standard (average)	5.0 mg/l
DO saturation at 29°C	7.7 mg/l
Background DO deficit	0.7 mg/l
Allowable deficit	2.0 mg/l

Included in the 0.7 mg/l DO deficit for background are the effects of algal growth and benthic demand. In using this deficit, it was assumed that the algal populations were under control and that the benthic demand resulting from wastewater sludge deposits had been substantially reduced from existing conditions. The UOD loadings were based upon maintaining 5.0 mg/l of DO averaged over the tidal cycle.

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* The ultimate oxygen demand represents the sum of unoxidized carbon and nitrogen

Table X-5

UOD LOADINGS FOR POTOMAC ESTUARY

Based Upon Maintaining 5.0 mg/l DO
Freshwater Inflow = 300 cfs (after water supply diversion)
Water temperature = 29°C

Zone	Allowable UOD (lbs/day)
I-a	4,000
I-b	3,000*
I-c	75,000
II	190,000
III	380,000

* The loading increases with increase in waste flow (See text for more details).

Subzone I-c currently receives wastewater effluents from the Blue Plains Sewage Treatment Plant which serves the District of Columbia and surrounding portions of Maryland and Virginia, and from sewage treatment plants in Arlington, Alexandria, and Fairfax County, Virginia. As shown in Table X-5, a maximum UOD loading of approximately 75,000 lbs/day may be discharged into Subzone I-c regardless of the alternative investigated.

The effect of eliminating effluent aeration as a treatment process was determined for Subzone I-c. If a dissolved oxygen concentration of 2.0 mg/l instead of 6.0 mg/l in the wastewater is assumed, the allowable UOD loading in Subzone I-c would be about 60,000 lbs/day, or a reduction of 20 percent.

Two other subzones within Zone I, Subzone I-a of the Potomac Estuary in the vicinity of Chain Bridge and Subzone I-b of the Anacostia tidal river, were evaluated separately for Alternatives II and III because their waste assimilative capacities are quite limited. The allowable UOD loading for Subzone I-a based upon a freshwater flow of 200 to 300 cfs is 4000 lbs/day. The lack of adequate transport under low-flow conditions, and more important, the limited reaeration capability due to the considerable depth of water in this area greatly reduce the maximum allowable UOD loadings in the Potomac near Chain Bridge. CTSL mathematical modeling studies have shown that the allowable UOD load to this portion of the estuary increases substantially with increasing water supply flow withdrawals. This relationship, which is due to the direct removal of UOD before it is exerted in the receiving water, is shown below:

Net Flow into the Estuary* (cfs)	Allowable UOD (lbs/day)
+ 250	4000
- 500	6000
-1250	12000
-2000	18000

The allowable UOD loadings in Subzone I-b, which is the upper Anacostia tidal river (Alternative II), are given for the three waste flow conditions as follows:

Wastewater Flow (mgd)	Allowable UOD (lbs/day)
68	3000
126	6000
185	9000

Again the absence of adequate transport and dilution restricts the waste assimilative capacity of the Anacostia tidal river. The increase in the allowable UOD shown above can be attributed to the progressive increase in wastewater discharges which greatly exceeds the natural inflow to the Anacostia tidal system in importance. In effect, the proposed wastewater discharge would substantially increase the downstream advective movement and the assimilative capacity of the Anacostia River.

---

* Negative net flows represent water supply withdrawal from the estuary assuming that all freshwater inflow from the upper basin, except for a base flow of 200 mgd, has already been diverted.

Zone II of the Potomac Estuary currently receives effluents from the Piscataway and Lower Potomac wastewater treatment facilities via the Piscataway Creek and Gunston Cove embayments. By 1980, a third facility serving Mattawoman Creek basin in Charles County will also discharge into Zone II near Indian Head. Two basic schemes were investigated to determine UOD loadings in this zone. One scheme (Alternative V) assumes that all effluents discharge directly into the Potomac main channel whereas the other (Alternative I) assumes that the Piscataway Creek and Gunston Cove embayments continue to receive treated effluents from their respective wastewater plants.

According to Table X-5, the maximum UOD which can be discharged into Zone II and still permit the DO standard of 5.0 mg/l to be realized is 190,000 lbs/day. It should be noted that prior to determination of this allowable load, the residual or carryover effects of Zone I and Zone III loadings upon Zone II were determined and included.

If Piscataway Creek and Gunston Cove receive the wastewater effluents projected in Alternative I, the maximum allowable UOD loadings will be reduced considerably when compared to Zone II loadings. The relative inability of these embayments to assimilate organic wastewater is reflected in the data shown below:

UOD LOADINGS FOR PISCATAWAY CREEK AND GUNSTON COVE

Piscataway Creek		Gunston Cove	
Flow (mgd)	Maximum UOD Load (lbs/day)	Flow (mgd)	Maximum UOD Load (lbs/day)
24	10,000	50	7,000
49	10,000	103	11,000
79	12,000	170	16,000

Since the physical characteristics for each embayment vary widely, it must be emphasized that separate determinations of loadings will be required for embayments other than those given above.

Because of the stringent loading requirements associated with discharges to embayments, it would appear advisable to discharge wastewater effluents directly to the Potomac (as in Alternative V) and utilize the additional dilution and transport capability it affords.

There are at present no significant wastewater discharges within Zone III of the Potomac Estuary; however, a treatment facility to serve the Occoquan watershed in Virginia has been proposed for construction by 1980. Moreover, it was assumed that a facility at Port Tobacco, Maryland, would also be in existence prior to the year 2000. With Zone II receiving its allowable UOD load (190,000 lbs/day) and deducting the necessary carryover effects, the allowable UOD loading for Zone III was estimated at 380,000 lbs/day (Table X-5).

E. PHOSPHORUS

Simulation of phosphorus discharges in the Potomac Estuary was made using the mathematical model with second-order reaction kinetics previously described. Included in the model was a phosphorus deposition rate of 0.05 mg/day at a temperature of 29°C. The allowable phosphorus loadings in pounds per day were determined based on maintaining an average of 0.067 mg/l of phosphorus (P) within Zones I and II and 0.03 mg/l (P) within Zone III and all embayments. All effluents were assumed to be of the same concentration. While various freshwater inflow rates (before water supply diversions) between 300 cfs and 1800 cfs were investigated, their effect on the allowable phosphorus loadings appeared to be quite small.

The allowable phosphorus loading for Subzone I-c of the Potomac Estuary is 900 lbs/day as shown in Table X-6. It should be noted that this loading remains about the same for each alternative investigated.

When Alternative III was considered, the limited waste assimilative capacity of the Potomac Estuary in Subzone I-a near Chain Bridge became evident. For a freshwater flow of 300 cfs, the allowable phosphorus loading to this area was determined to be 200 lbs/day. If water supply withdrawals are assumed, a certain portion of the phosphorus will be removed directly, thereby increasing the allowable load from wastewater

Table X-6

PHOSPHORUS LOADINGS FOR POTOMAC ESTUARY

Freshwater Inflow = 300 cfs (after water supply diversion)

Zone	Allowable Phosphorus (lbs/day
I-a	200
I-b	85*
I-c	900
II	1500
III	2000

* The loading in this zone is sensitive to wastewater flow as described in the text of this report.

effluents. The relationship of allowable phosphorus load to rate of withdrawal is presented in the following table:

Net Flow Into Estuary (cfs)	Allowable Phosphorus Loadings (lbs/day)
+ 300	200
- 500	300
-1250	400
-2000	500

For Alternative II, which includes a discharge into the Anacostia River, simulation runs indicate that the minimum transport and dilution greatly restricts the allowable phosphorus load that may be discharged into the Anacostia tidal system. As in the case of UOD, the phosphorus loadings into Subzone I-b are also a function of wastewater as follows:

Wastewater Flow (mgd)	Allowable Phosphorus Loadings (lbs/day)
68	85
126	135
185	180

As shown in Table X-6, the allowable phosphorus loading into Zone II of the Potomac is 1500 lbs/day. The appropriate carryover effects from both Zones I and III were incorporated into the phosphorus analysis for Zone II.

When wastewater effluents are discharged into the embayments of Zone II, there is a much larger increase in phosphorus concentration for a given phosphorus loading. As an example, assuming 1980 wastewater flow data and a 1000 cfs inflow, if the effluent contains 10 mg/l of phosphorus, the result in the Piscataway embayment would be as follows:

Discharge Location	Increase in Phosphorus Upper End of Embayment (mg/l)	Increase in Phosphorus Lower End of Embayment (mg/l)
Into Embayment	3.93	1.22
Into Main Potomac	0.78	0.92

A similar tabulation for Gunston Cove, again assuming 1980 conditions, follows:

Discharge Location	Increase in Phosphorus Upper End of Embayment (mg/l)	Increase in Phosphorus Lower End of Embayment (mg/l)
Into Embayment	8.62	0.61
Into Main Potomac	0.49	0.62

The above tabulations clearly show that concentrations in the upper end of the embayments can be drastically reduced by diverting discharges to the main Potomac. However, they also show that the phosphorus concentrations in the lower end of the embayments are considerably less affected. This can be attributed to the tidal exchange between the main Potomac and the embayments.

If discharges projected in Alternative I are made to the upper end of the Piscataway Creek and Gunston Cove embayments, the maximum allowable phosphorus loadings are as follows:

PHOSPHORUS LOADINGS TO EMBAYMENTS

Piscataway Creek		Gunston Cove	
Flow (mgd)	Maximum Phosphorus Load (lbs/day)	Flow (mgd)	Maximum Phosphorus Load (lbs/day)
24	35	50	35
49	50	103	60
79	65	170	140

The loadings given apply to these embayments only. A separate determination will be required for other embayments because of different physical configuration. The effect of the main Potomac on the embayments was previously demonstrated by Jaworski and Johnson in a preliminary study of the Piscataway embayment [42].

It can be concluded that there is a significant advantage in discharging wastewater effluents into the main channel (Zone II) from the standpoint of phosphorus buildup. Moreover, it appears that with the lack of transport in the embayments, the allowable phosphorus concentration in discharges to the embayments begins to approach the developed criteria.

In order to realize the phosphorus criterion for Zone III of the Potomac Estuary (0.03 mg/l), the maximum phosphorus loading from wastewater effluents within this zone was determined to be 2,000 lbs/day as shown in Table X-6.

Using phosphorus as a tracer, simulation runs were made to determine how quickly any component in the wastewater discharge could reach the proposed estuary water intake. Table X-7 shows that in the extreme case investigated, about 4 days would elapse before detection there. For the projected year 2020, wastewater discharges and a river flow of 1800 cfs, the time would be increased to 8 days.

Table X-7

INTRUSION TIMES FOR PHOSPHORUS INTO ESTUARY WATER INTAKE

Wastewater Alternative I

Year	Net Inflow	Days Required to Detect an Increase in Phosphorus at Water Intake
1980	+1250	--*
1980	+ 250	--*
1980	- 500	10
2000	+ 500	--*
2000	- 500	9
2000	-1000	5
2020	- 500	8
2020	-1500	5
2020	-2000	4

* With a positive net inflow, there was no measurable intrusion into the intake.

F. NITROGEN

Inorganic nitrogen was simulated using a mathematical model which had already been verified based upon observed data. For purposes of developing zonal loadings, the total inorganic nitrogen was assumed to behave conservatively. Since nitrogen appears to be limiting the rate of algal growth in Zones II and III, more stringent criteria were adopted for those areas. The upper nitrogen concentration limits used for Zones I, II, and III were 0.5, 0.4, and 0.3 mg/l respectively at a temperature of 29°C. With these levels of inorganic nitrogen, some algal growth will occur but nuisance conditions should be prevented. The net estuary inflow, water supply withdrawal rates, population benchmarks, and alternative wastewater treatment schemes incorporated in the analysis of nitrogen were identical to those used for determining phosphorus loadings.

The allowable nitrogen loading for Subzone I-c of the Potomac Estuary is 3,400 lbs/day (Table X-8). For Alternative III and a freshwater inflow of 300 cfs, Subzone I-a can receive and adequately assimilate 1,000 lbs/day of nitrogen from wastewater effluents. If nitrogen is removed from this portion of the estuary via water supply withdrawals, the allowable nitrogen loadings will, of course, increase in a manner similar to that shown previously for UOD and phosphorus.

Table X-8

NITROGEN LOADINGS FOR POTOMAC ESTUARY
Freshwater Inflow = 300 cfs (after water supply diversion)

Zone	Allowable Nitrogen (lbs/day)
I-a	1000
I-b	300*
I-c	3400
II	5800
III	9000

* The loading in this zone is sensitive to waste flow as described in the text of this report.

Allowable nitrogen loadings for Subzone I-b, which is the upper Anacostia tidal river, are also a function of wastewater flow and are as follows:

Flow (mgd)	Allowable Nitrogen (lbs/day)
68	300
126	550
185	800

With all major wastewater effluents discharging to the main channel, Zone II of the Potomac Estuary can receive 5800 lbs/day of inorganic nitrogen (Table X-8) and still maintain the criterion of 0.4 mg/1. As shown in Table X-8, the allowable nitrogen loading for Zone III of the Potomac is 9000 lbs/day.

The importance of nitrogen as a potential rate-limiting nutrient within Zone II must be considered when evaluating the loading requirements for embayments such as Piscataway Creek and Gunston Cove. As in the case of phosphorus, the lack of movement from the head end of the embayments necessitates reducing the nitrogen concentration in wastewater effluents to a level approaching the established criteria.

For discharges made to the upper end of the embayments for Alternative I, the maximum allowable nitrogen loadings are:

NITROGEN LOADINGS TO EMBAYMENTS

Piscataway		Gunston Cove	
Flow (mgd)	Maximum Nitrogen Load (lbs/day)	Flow (mgd)	Maximum Nitrogen Load (lbs/day)
24	120	50	130
49	170	103	270
79	270	170	460

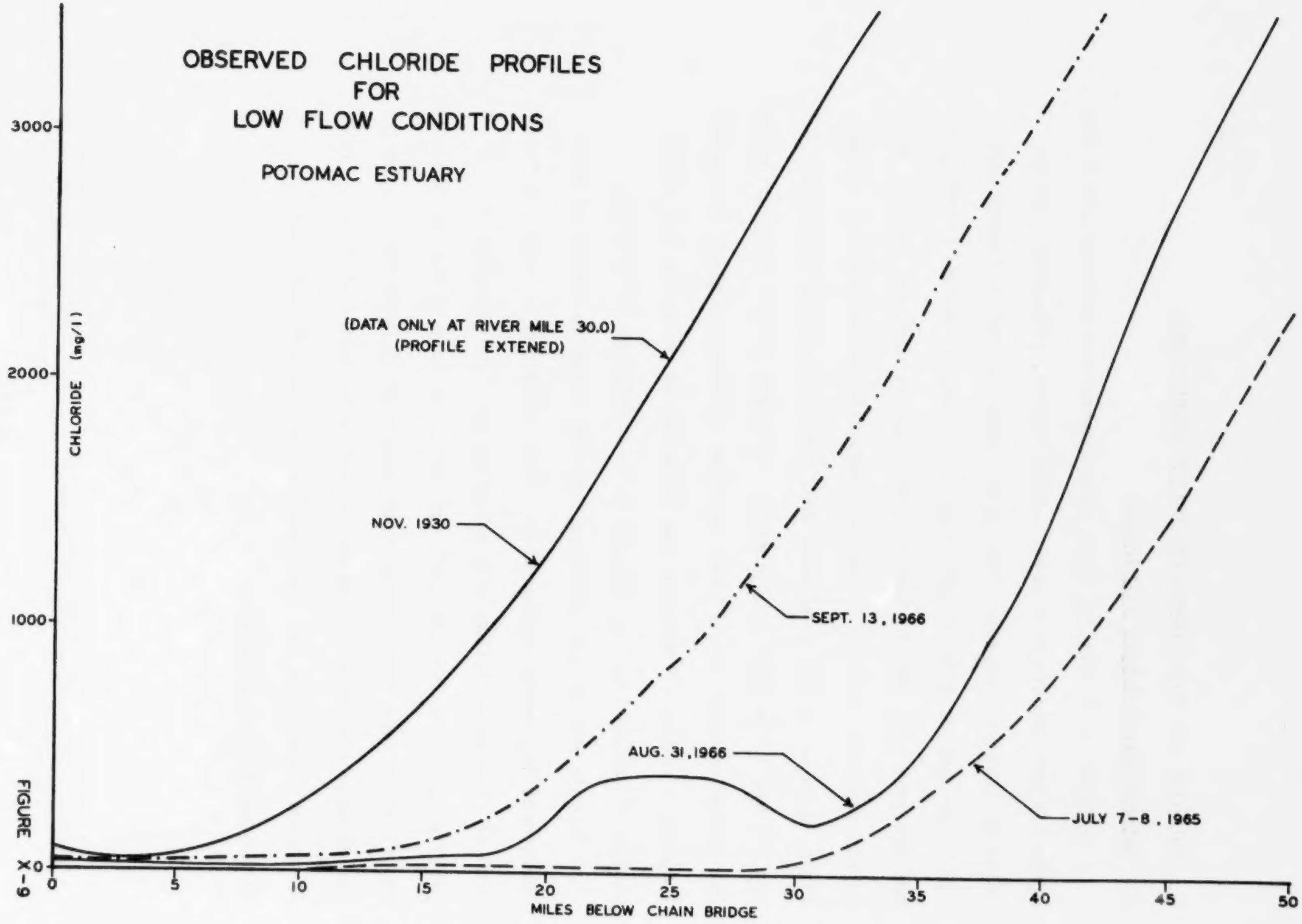
Independent determinations of nitrogen loadings must be made for other embayments because of varying hydrography and tidal characteristics. In view of this stringent allowable loading, a definite advantage is evident in discharging into the main channel.

G. CHLORIDE AND TOTAL DISSOLVED SOLIDS SIMULATIONS

1. Estuary Water Supply Withdrawal

In March 1969, Hetling [43] investigated the possible use of the upper Potomac Estuary as a water supply source, primarily from the chloride intrusion aspect. From this study, it was concluded that (1) under most critical summer-flow conditions on record (1930-1931) and the year 2010 demand, the estuary could be used for potable water supply purposes, and (2) if the wastewater is discharged out of the basin, such as to the Chesapeake Bay, the water supply potential of the estuary is reduced considerably. In light of the large projected wastewater volumes in the lower counties of Virginia along the upper Potomac, a review of the possible intrusion of chlorides and total dissolved solids into the estuary water intake was undertaken.

Data in Figure X-9 indicate that the chloride intrusion from Chesapeake Bay varies appreciably. This variation is mainly a function of freshwater inflow rate and duration. The November 1930 profile shows the farthest upstream intrusion as a result of prolonged low flows of less than 700 cfs from July through November. Although the drought conditions in September 1966 were more severe with flows of approximately 220 cfs, the duration was shorter and hence the intrusion was not as great.


OBSERVED CHLORIDE PROFILES FOR LOW FLOW CONDITIONS

POTOMAC ESTUARY

FIGURE X-9

Using four historic low-flow conditions, the rate of intrusion was calculated as follows:

Flows (cfs)	Upstream Movement (miles/day)
5000	0.00
1100	0.07
580	0.21
214	0.71

The above tabulation clearly shows the effect of freshwater inflow on the rate of the chloride intrusion from the Chesapeake Bay.

The intrusion of chlorides and total dissolved solids was simulated using the FWQA Dynamic Estuary Quality Model. For Alternatives I and IV, the simulations were made assuming the following freshwater inflows and water supply withdrawals:

	Freshwater Inflow at Great Falls (cfs)	Water Supply Withdrawal (cfs)	Net Flow Into the Estuary* (cfs)
Year 1980	1870	870	+1000
	1120	870	+ 250
	370	870	- 500
Year 2000	1750	1500	+ 250
	1000	1500	- 500
	250	1500	-1250
Year 2020	1900	2400	- 500
	1150	2400	-1250
	400	2400	-2000

* Negative net flow represents withdrawal from estuary for water supply

Two sets of initial conditions were used for each simulation: (1) an initial chloride wedge position as observed on September 13, 1966, and (2) a less severe condition using July 7-8, 1965, observations. The upper end of the chloride wedges under these two conditions is shown in Figure X-9.

To obtain the initial conditions for total dissolved solids (TDS), a relationship between TDS and chlorides was established from existing data as follows:

TDS (mg/l) = 1.69 Chlorides (mg/l) + 300

Boundary and loading conditions used in the simulations are itemized below:

	1966 Wedge	1965 Wedge
Chesapeake Bay chloride concentration	11000 mg/l	9000 mg/l
Chesapeake Bay TDS concentration	18000 mg/l	14000 mg/l
Freshwater inflow chloride concentration	30 mg/l	15 mg/l
Freshwater inflow TDS concentration	160 mg/l	160 mg/l
Wastewater TDS concentration*	300 mg/l	300 mg/l
Water use chloride increment	25 mg/l	25 mg/l
Water use TDS increment (Run 1)	40 mg/l	40 mg/l
Water use TDS increment (Run 2)	240 mg/l	240 mg/l

Currently the average concentration of chlorides and TDS in the wastewater effluents are about 40 and 300 mg/l, respectively. The above 40 and 240 increments for TDS are well within the range of accepted concentrations in the effluent of 200 to 400 mg/l. In this study, maximum upper limits for municipal water supply of 250 and 500 mg/l of chlorides and TDS respectively in the blended mix of estuary water and freshwater inflow were used as recommended by the U. S. Public Health Service [44].

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* The total TDS increase from water intake to wastewater discharge is currently about 140 mg/l

With the concentration of TDS in both the estuary and the wastewater effluent higher than for chlorides, the restricting limitation on the use of the estuary is TDS. This finding is also supported by Hydroscience [45] in their preliminary report on the feasibility of the Potomac Estuary as a supplemental water supply source.

Summaries of the results of the TDS simulations for the initial conditions of July 7-8, 1965, and September 13, 1966, are given in Tables X-9 and X-10. Based on data summarized in these two tables as well as from other simulations runs, it can be concluded that:

1. Even with no water supply withdrawals from the estuary, chloride and TDS intrusion will occur farther upstream in the Potomac Estuary as a result of the larger percentages of total wastewater volumes discharged farther downstream and projected increases in consumptive loss. Currently, less than 20 mgd is discharged into saline waters. By 2020, approximately 31 percent of the wastewater or over 400 mgd will be discharged into the saltwater wedge. The consumptive loss, which is water supply withdrawal minus wastewater discharge, is projected to increase as shown below:

Year	Consumptive Loss (mgd)
1966*	44
1980	83
2000	148
2020	226

* During the month of August in which the flow into the estuary was 538 cfs, the consumptive loss was about 13.5 percent

This increased downstream discharge, coupled with the above increased consumptive loss will reduce the net seaward flow in the upper estuary even without any water supply withdrawal.

2. The number of days that the estuary can be used for water supply depends mainly on (a) duration and magnitude of drought conditions, (b) location of wastewater treatment facility discharges, and (c) position of the salt wedge before low-flow conditions begin.

3. The effect of the incremental increase in TDS in the wastewater on the concentration at Chain Bridge is not significant for the upper or lower wedge positions for Alternative IV. The number of days that the estuary could be used for a water supply did not vary if 40 or 240 mg/l was used. The major effect on the concentration was the intrusion from the Chesapeake Bay which is controlled by freshwater inflow and wastewater discharge locations (Table X-9).

For the upper wedge position, as given in Table X-10, the effect of the concentration of TDS in the effluent is more significant especially for Alternative I and the year 2020. The time was reduced by 24 days when the TDS increment was increased from 40 to 240 mg/l.

4. With the salt wedge in the upper position as of September 13, 1966, using the TDS criterion of 500 mg/l in the blended water, Alternative I, and with less than 400 cfs coming over Great Falls before

water supply withdrawal, the estuary could be used for water supply for the following periods:

Year	40 mg/1 Increment (days of use)	240 mg/1 Increment (days of use)
1980	> 166	> 166
2000	90	35
2020	45	15

This reduction in usage between 1980 and 2020 is primarily the result of increased incursion due to reduced net seaward flow and increased consumptive losses. For the lower position or the July 7-8, 1968, location of the wedge and the other conditions given above, the estuary could be used for water supply for the following periods:

Year	40 mg/1 Increment (days of use)	240 mg/1 Increment (days of use)
1980	> 166	> 166
2000	140	45
2020	95	20

The above reduction with time again reflects the increasing downstream discharges and the increasing consumptive losses.

5. Assuming about 1800 cfs freshwater inflow and the September 13, 1966, initial wedge location, the estuary can be used as a water supply source for over 166 days (the upper limit of the simulation period) for both chlorides and TDS for all three population benchmark years 1980, 2000, and 2020.

6. The number of days that the estuary can be used as a water supply for the year 2020 beginning with the September 13, 1966, wedge location as a function of freshwater flow is given below:

MAXIMUM DAYS OF USE OF ESTUARY

Freshwater Inflow Before Water Supply Withdrawal (cfs)	Alternative I Water Use Increment of TDS 40 mg/l (days)	Alternative I Water Use Increment of TDS 240 mg/l (days)	Alternative IV Water Use Increment of TDS 40 mg/l (days)	Alternative IV Water Use Increment of TDS 240 mg/l (days)
400	45	15	18	18
1100	>166	42	>166	41
1800	>166	>166	>166	>166

7. Since the projected water supply needs for the year 2020 cannot be met by either the upper basin with seven reservoirs or the estuary alone, both sources will be needed to supply the water needs for the Washington metropolitan area.

8. It is necessary to coordinate both the water supply and wastewater treatment requirements for planning in the Washington area since use of the estuary for water supply purposes is dependent on the location and distribution of wastewater discharges.

Table X-9

TIME, IN DAYS, TO REACH INDICATED CONCENTRATION OF TOTAL DISSOLVED SOLIDS IN ESTUARY AT PROPOSED WATER INTAKE NEAR CHAIN BRIDGE
(Initial Conditions as of July 7-8, 1965)

	1980		2000		2020	
	Alt. I	Alt. IV	Alt. I	Alt. IV	Alt. I	Alt. IV
Freshwater Flow*	1000 cfs		250 cfs		-500 cfs	
Water Use Increment 40 mg/l of TDS						
TDS (500) mg/l	>166	>166	>166	>166	>166	132
TDS (1000) mg/l	>166	>166	>166	>166	>166	>166
TDS (1500) mg/l	>166	>166	>166	>166	>166	>166
Water Use Increment 240 mg/l of TDS						
TDS (500) mg/l	>166	>166	>166	>166	>166	162
TDS (1000) mg/l	>166	>166	>166	>166	>166	>166
TDS (1500) mg/l	>166	>166	>166	>166	>166	>166
Freshwater Flow	250 cfs		-500 cfs		-1250 cfs	
Water Use Increment 40 mg/l of TDS						
TDS (500) mg/l	>166	>166	>166	124	>166	63
TDS (1000) mg/l	>166	>166	>166	>166	>166	100
TDS (1500) mg/l	>166	>166	>166	>166	>166	126
Water Use Increment 240 mg/l of TDS						
TDS (500) mg/l	>166	>166	>166	123	32	60
TDS (1000) mg/l	>166	>166	>166	>166	>166	97
TDS (1500) mg/l	>166	>166	>166	>166	>166	122
Freshwater Flow	-500 cfs		-1250 cfs		-2000 cfs	
Water Use Increment 40 mg/l of TDS						
TDS (500) mg/l	>166	118	130	58	84	43
TDS (1000) mg/l	>166	>166	>166	88	130	68
TDS (1500) mg/l	>166	>166	>166	107	159	86
Water Use Increment 240 mg/l of TDS						
TDS (500) mg/l	83	117	126	57	15	43
TDS (1000) mg/l	>166	160	147	87	130	68
TDS (1500) mg/l	>166	>166	>166	106	159	86

* Inflow to estuary after water supply withdrawal

Table X-10

TIME, IN DAYS, TO REACH INDICATED CONCENTRATION OF TOTAL DISSOLVED SOLIDS IN ESTUARY AT PROPOSED WATER INTAKE NEAR CHAIN BRIDGE

(Initial Conditions as of September 13, 1966)

	1980		2000		2020	
	Alt. I	Alt. IV	Alt. I	Alt. IV	Alt. I	Alt. IV
Freshwater Flow*	1000 cfs		250 cfs		-500 cfs	
Water Use Increment 40 mg/l of TDS						
TDS (500) mg/l	>166	>166	>166	>166	>166	132
TDS (1000) mg/l	>166	>166	>166	>166	>166	>166
TDS (1500) mg/l	>166	>166	>166	>166	>166	>166
Water Use Increment 240 mg/l of TDS						
TDS (500) mg/l	>166	>166	>166	>166	>166	162
TDS (1000) mg/l	>166	>166	>166	>166	>166	>166
TDS (1500) mg/l	>166	>166	>166	>166	>166	>166
Freshwater Flow	250 cfs		-500 cfs		-1250 cfs	
Water Use Increment 40 mg/l of TDS						
TDS (500) mg/l	>166	>166	>166	124	>166	63
TDS (1000) mg/l	>166	>166	>166	>166	>166	100
TDS (1500) mg/l	>166	>166	>166	>166	>166	126
Water Use Increment 240 mg/l of TDS						
TDS (500) mg/l	>166	>166	>166	123	32	60
TDS (1000) mg/l	>166	>166	>166	>166	>166	97
TDS (1500) mg/l	>166	>166	>166	>166	>166	122
Freshwater Flow	-500 cfs		-1250 cfs		-2000 cfs	
Water Use Increment 40 mg/l of TDS						
TDS (500) mg/l	>166	118	130	58	84	43
TDS (1000) mg/l	>166	>166	>166	88	130	68
TDS (1500) mg/l	>166	>166	>166	107	159	86
Water Use Increment 240 mg/l of TDS						
TDS (500) mg/l	83	117	126	57	15	43
TDS (1000) mg/l	>166	160	147	87	130	68
TDS (1500) mg/l	>166	>166	>166	106	159	85

* Inflow to estuary after water supply withdrawal

2. Direct Reuse of Treated Wastewater

In the system where treated wastewater is discharged into the freshwater estuary, intrusion of salt from Chesapeake Bay is one of the major restrictions if the upper estuary is to be used as a potable water supply. The direct reuse system (that is, going directly from the advanced wastewater treatment facility to the water supply facility) removes this restriction.

Using the water requirements for the year 2020 and conditions as defined in the previous section, simulations were made with the direct reuse system to determine the rate of buildup of both chlorides and TDS. The results of these simulations for various flow conditions are presented below:

		Equilibrium Concentrations		
Water from Upper Basin (cfs)	Water from Direct Reuse (cfs)	Chlorides max. Concentration (mg/l)	40 mg/l of TDS Increase (mg/l)	240 mg/l of TDS Increase (mg/l)
400	2000	140	360	1360
1150	1250	42	203	421
1900	500	22	171	233

The equilibrium concentrations or maximum concentrations to which the system would build up with partial direct recycling usually were reached in less than 20 days except for the first flow condition (400 cfs from Great Falls) in which 40 days were required.

The above tabulation indicates that direct reuse is a feasible solution to the future water supply needs of the Washington metropolitan area with respect to TDS and chlorides. The only restriction is that with over 80 percent of the water supply from renovated wastewater, the maximum combined buildup in TDS from both the water supply and wastewater treatment facilities has to be less than 65 mg/l. For a flow of 670 cfs (the seven-day-low-flow with a recurrence interval of once-in-50-years) or with approximately 70 percent of the water supply from renovated wastewater, the maximum TDS buildup would have to be restricted to 140 mg/l. As reported earlier, this is the current buildup in the entire water use system.

Based on data obtained from the AWT pilot plant operation at Blue Plains [46], the TDS, excluding the bicarbonate system, is not anticipated to increase and in fact may decrease. Since the bicarbonate concentration can be controlled by proper selection of unit processes of the AWT treatment facilities, the 140 mg/l increment can readily be maintained.

The direct reuse concept has the following advantages:

(1) Effects of intrusion from the Chesapeake Bay are eliminated,

(2) Need for the protection of the upper estuary from accidental spills, urban runoff, storm and combined sewer overflows with respect to water supply is eliminated,

(3) Restriction on the location of wastewater facilities with respect to water supply needs is eliminated,

(4) With proper planning, the need for massive wastewater collection and water distribution systems can be reduced. For example, both facilities can be located in the upper Potomac area with reuse being instituted whenever needed. During high-flow periods, the effluent may be discharged into the Chesapeake and Ohio Canal and conveyed past the downstream water intake.

(5) The need for the proposed upstream impoundments for water supply in the Washington area would be eliminated.

The major disadvantages are:

(1) Ammonia nitrogen conversion or removal will be required at temperatures approaching 5°C. Technology for this requirement is not fully developed at the present time.

(2) With the potential buildup of TDS, unit process will have to be carefully selected.

(3) A high degree of operation efficiency, including "fail safe" concepts, must be maintained at both the wastewater and the water supply facilities.

The direct reuse concept has great potential. However, there are many aspects which need to be investigated. These concepts could also be readily applied to small areas such as the Occoquan watershed, a sub-basin of the Potomac below Washington, and the Patuxent River Basin, a watershed between Baltimore and Washington.

CHAPTER XI

WASTEWATER TREATMENT FACILITIES AND COSTS

A. TREATMENT CONSIDERATIONS

To meet the carbon (UOD), nitrogen, and phosphorus requirements previously specified, a high degree of wastewater treatment will be required for Zone I. Based upon the performance of the FWQA pilot plant at Blue Plains, Bishop [46] indicates that the following removal rates can be anticipated from April to November (winter operation reliability has not been demonstrated):

Parameter	After Treatment	% Removal
BOD_5	< 2.0	> 99
Nitrogen as N	1.0 - 2.0	90 - 95
Phosphorus as P	< 0.1	> 99

To achieve the above removals, the following unit process sequence could be selected:

(1) Primary settling and activated sludge,
(2) Biological nitrification,
(3) Biological denitrification,
(4) Lime treatment,
(5) Dual media filtration,
(6) Effluent breakpoint chlorination, and
(7) Effluent aeration.

The above unit processes can produce an effluent which will meet the removal requirements for phosphorus and ultimate oxygen demand. However, with respect to nitrogen removal for algal control, it appears that the requirement cannot be readily met. Since over 99 percent of phosphorus can be removed, it appears that with a combination having a high percentage of carbon removal and 90 percent nitrogen removal, such as the preceeding seven unit processes can provide, both the DO enhancement and algal control will be realized. At present, the need for activated carbon adsorption has not been adequately demonstrated.

An important aspect of wastewater treatment will be the additional effluent aeration required, especially in Zone I, or for large discharges into small embayments. For example, a discharge of 185 mgd into the Anacostia River will be over 35 times greater than the freshwater inflow during low-flow periods. Hence, to maintain a DO level of 5.0 mg/l, the discharge will have to have at least 5.0 mg/l of DO. The unit process for this effluent quality is included in all costs presented in this report.

Additional removal of inorganic nitrogen and carbon could be provided by activated carbon. The activated carbon beds become media for bacterial growths which convert some of the organic nitrogen to ammonia. The ammonia can then be removed by additional chlorination. Since the continued effectiveness of this additional nitrogen removal process is not well established, the effectiveness or the need for carbon adsorption as an additional wastewater unit process has not at present been established. Its utility appears to be more predicated on the use of the estuary as a water supply than for wastewater treatment.

B. WASTEWATER TREATMENT COSTS

Cost estimates for conventional secondary treatment and six advanced waste treatment (AWT) processes were developed for 15 present and planned facilities. The AWT processes considered include lime clarification with dual media filtration (for phosphorus removal and for additional carbon removal), carbon adsorption, biological nitrification and denitrification (for removal of ammonia and nitrate nitrogen respectively), and effluent aeration (to increase the DO from 1.0 to 6.0 mg/1). Capital costs and operation and maintenance (O & M) costs for each process were obtained chiefly from the Bechtel Corporation's report [47] on AWT at Blue Plains and cost data prepared by Smith and McMichael [48]. Where necessary, these costs were adjusted to reflect mid-1970 engineering indexes.

Cost data for specific years were determined by a computer systems program which incorporated equations describing the dollar per unit discharge relationship. One of the cost curves used is shown in Figure XI-1. Basic assumptions and alternative amortization and plant operation schemes included:

(1) Expenditures for new construction required in 1970, 1980, and 2000 are based upon design for conditions 10 or 20 years hence.

(2) In the case of existing treatment plants, construction of AWT units would begin in 1970 with O & M cost accruing from that time. Other plants were assumed to be constructed in 1980.

ACTIVATED SLUDGE COST

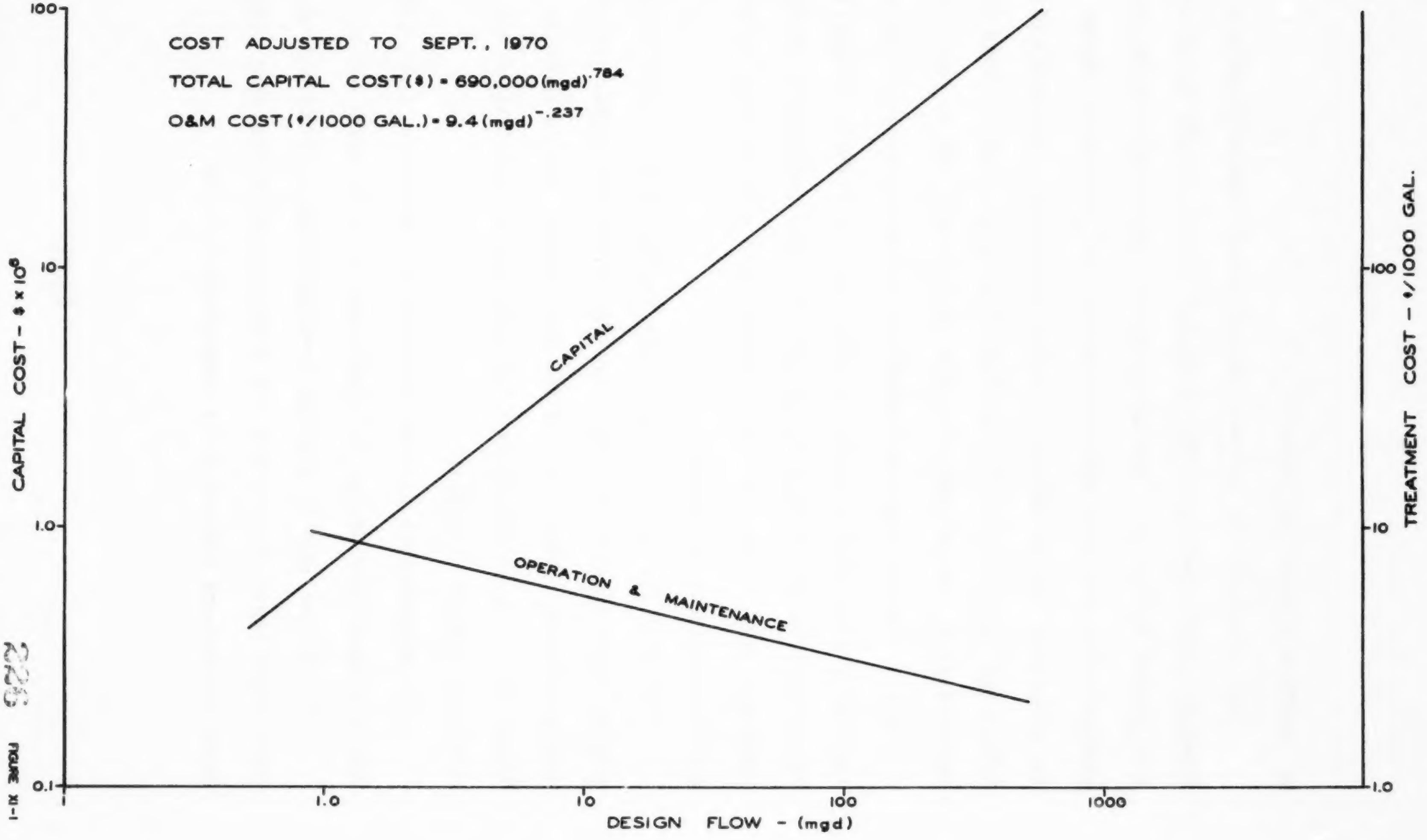


FIGURE XI-1

(3) If a new AWT plant is to be constructed in 1970, a 15-percent replacement of this plant would be necessary by 1980 in addition to required expansion. For the year 2000 construction, it was assumed that the entire original plant built in 1970 and 30 percent of the plant built in 1980 would be replaced.

(4) If a new AWT plant is to be constructed in 1980, 30-percent replacement would be provided for the year 2000 along with expansion to meet 2020 needs.

(5) With the exception of Arlington, conventional treatment units at the existing plants were considered to be new in 1970. The current capacity at Piscataway was assumed to be 30 mgd since construction of additional facilities is well under way.

(6) O & M costs for AWT units were based on 6-month and 12-month operating periods and the average projected waste flows for the specific time frame.

(7) The amortization of capital costs was assumed over a 20-year period with an interest rate of 5-1/8 percent.

Table XI-1 presents a summary of the treatment cost data for the upper Potomac Estuary through the year 2020.

Using Alternative III, the total present worth cost of wastewater treatment expenditures from 1970 to 2020 was determined to be $1,340 million (Table XI-1). If activated carbon is added, the cost will increase to $1,700 million. The annual cost basis for an average population of six million people reduces to approximately $11 per person per year. With the activated carbon units, the cost increases to $14 per person per year.

Capital cost expenditures and O & M costs are presented by unit process for the three periods (1) 1970-1980, (2) 1980-2000, and (3) 2000-2020 in Table XI-2. As can be seen in the table, the largest capital costs of the total initial cost of $2,272 million are $737 million for secondary and $463 million for activated carbon unit process, with the O & M cost being largest for the lime clarification and activated carbon processes.

With nitrification and denitrification required for only 7 months out of 12, an annual O & M savings of $3 million from 1970-1980, $4 million from 1980-2000, and $6 million from 2000-2020 can be realized. Continued studies will be required to further define the temporal removal requirements for nitrogen.

Table XI-1

TOTAL WASTEWATER TREATMENT COST
1970-2020
Alternative III

Unit Process	TPW* ($ x 10^6)	TAAC** ($ x 10^6)
Primary-secondary	457	13.5
Biological nitrification	247	13.8
Biological denitrification	133	9.4
Lime clarification	370	20.6
Dual media filtration	101	5.7
Effluent Aeration	10	0.6
Chlorination	22	1.2
Subtotal	1,340	$64.8
Activated Carbon	360	20.1
Total	1,700	$84.9

* Total present worth cost includes proposed secondary treatment expansion cost for Blue Plains

** Total average annual cost including operation and maintenance cost based on 12 months of operation

Table XI-2

INITIAL CAPITAL CONSTRUCTION
AND
OPERATION AND MAINTENANCE COSTS
1970-1980, 1980-2000, and 2000-2020 Time Periods

Unit Process	1970-1980		1980-2000		2000-2020	
	Capital ($\$x10^6$)	Other ($\$x10^3$)	Capital ($\$x10^6$)	Other ($\$x10^3$)	Capital ($\$x10^6$)	Other ($\$x10^3$)
Primary-secondary	236.11	4141.48	129.71	7413.07	371.11	11512.23
Biological nitrification	70.64	3968.66	84.53	7097.46	167.63	11044.23
Biological denitrification	62.11	427.29	71.84	759.32	148.24	1197.80
Lime clarification	69.31	8661.66	81.96	15573.46	166.12	24560.32
Dual media filtration	27.22	889.15	35.02	3064.69	66.09	4510.30
Chlorination	0.37	761.59	2.00	1328.37	3.55	2165.03
Effluent aeration	2.91	226.61	4.35	407.73	6.90	739.27
Subtotal	468.67	19176.44	409.49	35644.10	929.64	55729.18
Activated carbon	101.96	5931.92	118.38	10535.54	243.40	16643.79
Total	570.63	25108.36	527.87	46179.64	1173.04	72372.97

The tabulation below is a reduction of the initial capital and operation and maintenance costs to a per capita basis:

Item	1970-1980	1980-2000	2000-2020
Average Population	3,350,000	5,350,000	8,000,000
Total Initial Capital Cost/Time Period	$570,000,000	$528,000,000	$1,173,000,000
Capital Cost/Person/Year	$17.0	$4.9	$7.3
O & M Cost/Year	$25,100,000	$46,200,000	$72,400,000
O & M Cost/Person/Year	$7.5	$8.6	$9.1
Total Cost/Person/Year	$24.5	$13.5	$16.4

The above summary, which does include replacement cost, indicates that the cost of wastewater treatment in the upper Potomac Estuary is about $13 to $24/per person/per year. This expenditure, which includes the cost of the activated carbon process, will renovate the water to the chemical and microbiological qualities meeting drinking water standards.

CHAPTER XII

IMPLEMENTATION TO ACHIEVE WATER QUALITY STANDARDS

A. SEASONAL WASTE TREATMENT REQUIREMENTS

1. Ultimate Oxygen Demand

The maximum allowable UOD loadings presented in Chapter X for the three upper zones of the Potomac Estuary apply under warm temperature conditions. The effects of nitrogenous oxygen demanding substances on the dissolved oxygen budget were determined to be quite significant when water temperatures exceed 15°C. At the present time, approximately 250,000 lbs/day of nitrogenous oxygen demand is discharged in wastewater effluents as compared to about 200,000 lbs/day of carbonaceous demand. Therefore, during very warm periods when nitrification rates are high, the nitrogenous component of UOD exerts a greater effect on the dissolved oxygen resources than the carbonaceous material. In order to comply with the allowable UOD loadings shown previously, it is necessary to reduce drastically both the nitrogen and carbon levels at the wastewater treatment plants whenever temperatures exceed 15°C.

During cold weather periods when the ambient water temperature is less than 15°C, the effects of nitrification on the dissolved oxygen budget become negligible as reported in Chapter VI. Therefore, the need for removal or oxidation of ammonia in wastewater discharges is not required during these periods.

To prevent the accumulation of sludge deposits in the vicinity of sewage treatment outfalls during cooler weather and to maintain high DO levels under ice cover, a high degree of removal of suspended solids and carbonaceous oxygen demanding material must be continued. Suspended solids concentrations in the effluent should not exceed 15 mg/l, and a minimum of 90 percent of the carbonaceous oxygen demand should be removed on a year-around basis. Currently, about 72 percent of the UOD load before wastewater treatment is carbonaceous and the remaining 28 percent nitrogenous. Based upon this proportion of carbonaceous and nitrogenous components in raw sewage, the requirement for carbonaceous removal would translate to 70-percent UOD removal.

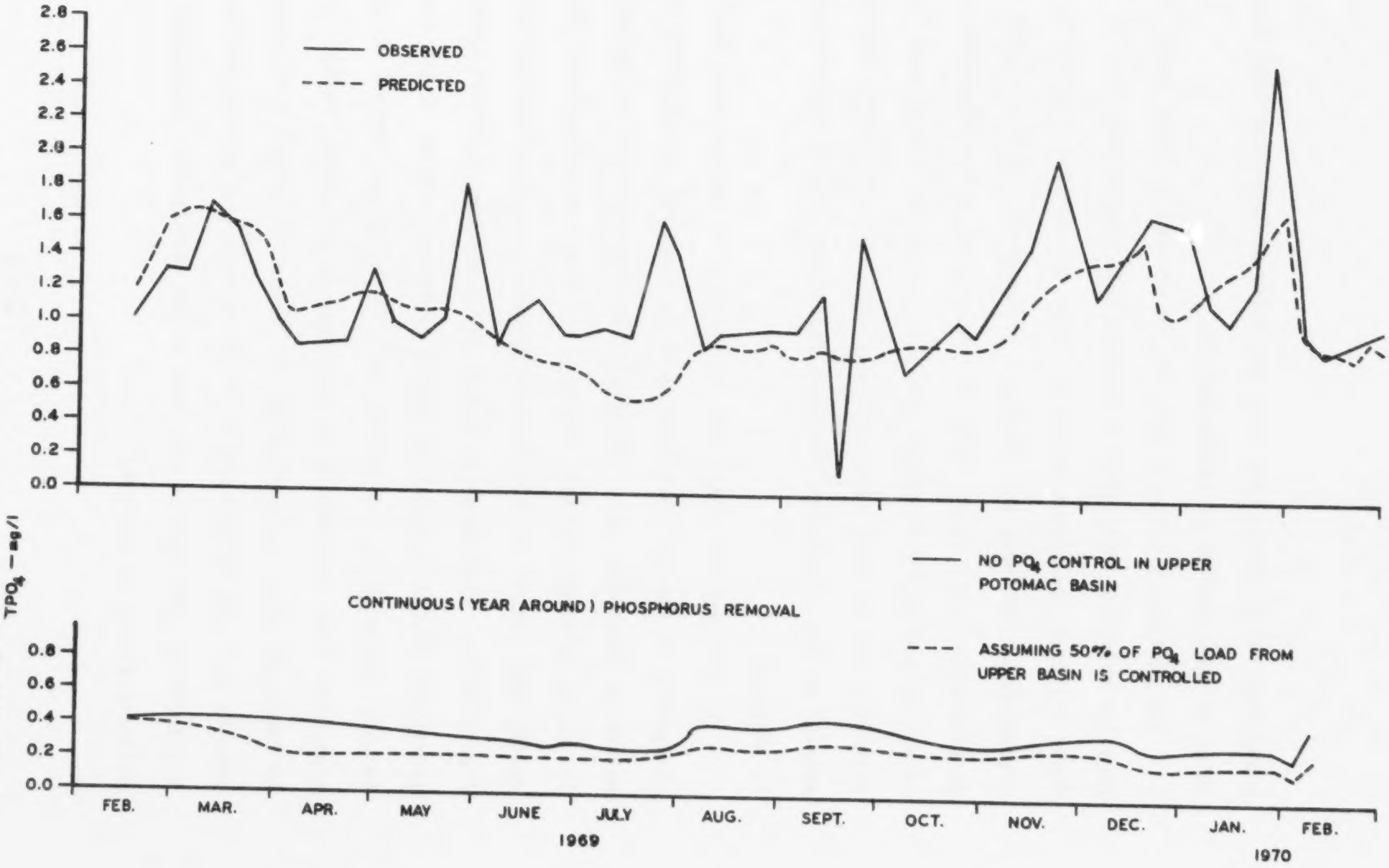
Since the quantity of dilution flows in the upper end of the tidal embayments is greatly limited, continuous aeration of major wastewater effluents discharged to these areas will be required.

2. Phosphorus

Of the various nutrients that have been associated with the eutrophication problem in the upper and middle reaches of the Potomac Estuary, phosphorus has been found to be most controllable, not only on a seasonal basis but on an annual basis as well. As presented in Chapter VII, approximately 60 to 96 percent of the total phosphorus load to the Potomac Estuary can be controlled depending upon the existing flow conditions. An additional reduction in the uncontrollable phosphorus load from the upper basin occurs in the upper estuary as a result of phosphorus being sorbed upon silt particles accompanying high flows, which is then removed by sedimentation.

The phosphorus criteria required to prevent nuisance algal blooms from occurring, as developed in Chapter VII, varied from 0.03 to 0.1 mg/l. These criteria are approximately an order of magnitude lower than the corresponding criteria for nitrogen. Because of these stringent criteria, particularly in the lower zones of the estuary, and the possibility of recycling previously deposited phosphorus from the bottom muds (this contribution has not been quantitatively defined), year-around phosphorus removal at the wastewater treatment facilities in the upper estuary will be necessary.

The mathematical model used to predict the annual distribution of phosphorus in the critical algal growing areas was verified based upon extensive phosphorus data collected from February 1969 to September 1970. The close agreement between observed and predicted phosphorus profiles during this period for the Potomac Estuary at Indian Head is shown in Figure XII-1. Also shown in Figure XII-1 are the predicted annual phosphorus profiles resulting from year-around removal in the upper estuary, assuming (1) no control and (2) 50-percent control of the phosphorus load originating in the upper Potomac River Basin. It can be concluded after an examination of Figure XII-1 that both phosphorus removal on a year-around basis in the estuary and partial control of the incoming load will be required if the recommended phosphorus criteria are to be achieved.



ANNUAL PHOSPHORUS PROFILES
POTOMAC ESTUARY AT INDIAN HEAD

FIGURE XII-1

In order to realize a 50-percent reduction in the current phosphorus load from the upper Potomac River, the wastewater contribution of 6100 lbs/day must be reduced to 700 lbs/day.

3. Nitrogen

As presented earlier in this chapter, the necessity for nitrogen control in wastewater discharges to enhance the dissolved oxygen in the Potomac Estuary is restricted to that time of year when water temperatures exceed 15°C. When evaluating inorganic nitrogen treatment requirements for the prevention of excessive algal blooms, controllability becomes a significant factor.

Mathematical model studies were used to investigate the effects of seasonal and continuous nitrogen removal at the wastewater facilities in the upper Potomac Estuary. Figure XII-2 shows the predicted annual nitrogen profiles for the Potomac Estuary at Indian Head, using the verified mathematical model, assuming (1) no nitrogen removal, (2) nitrogen removal during periods with temperatures above 15°C (April-November), and (3) year-around nitrogen removal. These profiles show that the recommended nitrogen criteria can be obtained during the critical growing periods with either seasonal or continuous nitrogen removal. Though it would be desirable to continuously maintain nitrogen concentrations at or below these criteria, the high flows from the upper basin during the winter and spring months contribute high nitrogen loadings which increase the nitrogen concentrations above acceptable levels regardless of treatment practices (Figure XII-2).

SIMULATED ANNUAL NITROGEN PROFILES

POTOMAC ESTUARY AT INDIAN HEAD

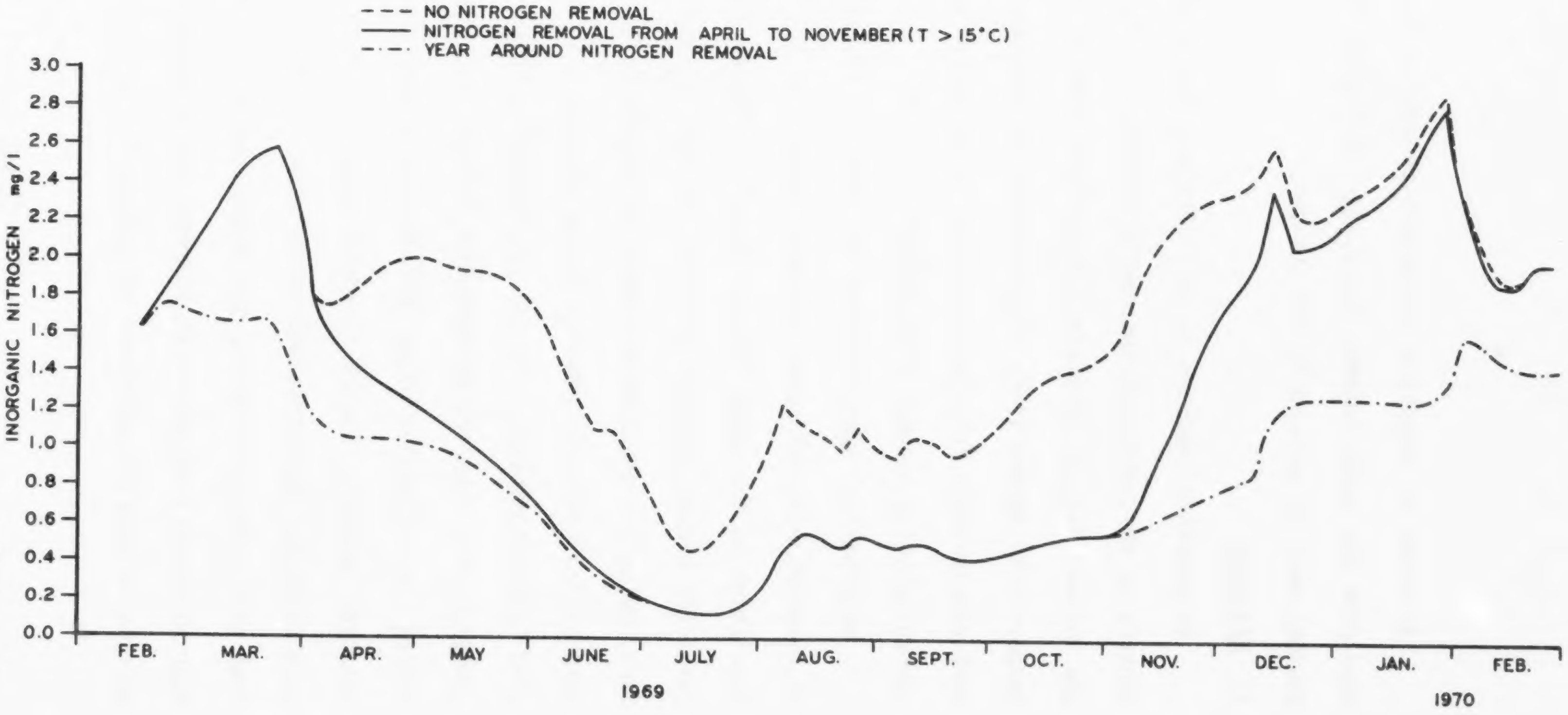


FIGURE XII-2

The controllable nitrogen from the wastewater treatment sources in the Washington metropolitan area is currently limited to about 60 percent of the total contribution from all sources. If nitrogen loadings increase as projected, the controllable amounts will also increase. Thus it appears that while nitrogen removal for algal control could be limited to periods when water temperatures in the estuary exceed 15°C, there may be a need for continuous control by the year 2000.

B. LOCATION OF WASTEWATER DISCHARGES

1. Wastewater Assimilation Versus Salinity Intrusion

Projected wastewater loadings are highest in Zone I, with allowable UOD, nitrogen, and phosphorus loadings the lowest of all three zones. The concentration of wastewater discharges in Zone I will require much higher removal rates there than will be necessary in Zones II and III.

When the high degree of wastewater treatment is considered, it would appear to be advantageous to discharge effluents farther downstream in the estuary. The assimilation and transport capacity in Zone II is about four times that of Zone I. However, when the estuary is considered as a water supply source, no major effluent discharges from the Washington metropolitan area should occur below the middle of Zone II (or below Gunston Cove). This downstream discharge limit is required to keep the salt wedge from moving upstream and causing chloride and TDS intrusion at the water intake.

If direct water reuse is eventually adopted, greater use of the assimilative and transport capacity of the estuary can be realized. Moreover, the farther down the estuary residual nutrient loads are discharged, the less favorable conditions will be for blue-green algae because of higher salinity.

2. Wastewater Discharges to the Embayments

All present treated waste effluents except that from Blue Plains discharge into the tidal portion of various embayments. As presented in the previous chapter, a high degree of UOD, nitrogen, and phosphorus removal will be required if the present embayment discharge practice is continued.

Based upon detailed analyses, including dye studies, of the Anacostia, Piscataway, and Gunston Cove tidal embayments, it appears that major discharges into the upper portion of small tidal embayments should have a maximum concentration of UOD, phosphorus, and nitrogen of 10, 0.2, and 1.0 mg/l, respectively. Effluents from these facilities will require renovation to approach ultimate wastewater renovation* (UWR) levels. Unless UWR is provided, effluents from Alexandria, Arlington, Piscataway, and the Lower Potomac facilities should be discharged into the main channel of the Potomac Estuary.

A detailed investigation is essential for each embayment to determine which option provides the lesser cost, an outfall to the main channel of the river or UWR. Future studies should also include consideration of effluent dispersion devices to minimize local effects.

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* Ultimate wastewater renovation can be defined as renovation of the wastewater to such a degree that it can be discharged into the receiving stream in unlimited quantities without restriction of the designated water resource use due to the lack of needed assimilative or transport capability of the stream. This implies that the quality of the effluent from a UWR plant conforms to the stream standards of the receiving waters.

C. FLOW REGULATION FOR WATER SUPPLY AND WATER QUALITY CONTROL

In the original plan for reservoir development in the upper Potomac River Basin, the U. S. Army Corps of Engineers recommended 16 impoundments including the large Seneca Dam [1]. These 16 reservoirs would regulate the flow of the Potomac at Washington to maintain an approximate 4600 cfs minimum and would provide the maximum daily water supply needs of the basin up to the year 2020. When the Seneca Reservoir is excluded, the remaining 15 impoundments would increase the dependable low flow to approximately 3600 cfs. This would be an adequate flow to meet the maximum monthly water supply demand for the Washington metropolitan area up to the year 2020.

In the original Corps of Engineers' plan, approximately $210 million or 42 percent of the $500 million construction cost was charged to water quality control. Of this $210 million water quality control construction cost, approximately $130 million was required to maintain Potomac Estuary water quality [1].

Davis [50], in his study of the water quality management problems of the Potomac Estuary, suggested that mechanical reoxygenation and low-flow augmentation provided the least costly solution to maintain a specific dissolved oxygen (DO) level. Although the costs for individual wastewater processes as presented by Davis have increased substantually, later investigations have indicated that algal control and nitrification requirements are presently the two most important considerations in water quality management for the upper estuary.

Nevertheless, the Davis studies demonstrate that DO standards could be maintained with a high degree of wastewater treatment at lower cost and with greater dependability than by flow regulation alone.

As summarized by Reinhardt [51], a program of water resource management must be flexible in order to make use of modern technological developments to meet current wastewater treatment requirements. The requirements developed in this study reflect not only a need for high carbonaceous BOD removals but also for nutrient removals to control algal growth. Low-flow augmentation for nutrient control will not be effective since the total nutrient loading in pounds per day entering the estuary is the primary factor to be considered in algal control. This insensitivity to flow is especially pronounced in the middle reach where the volume of the estuary is large, advective movement slight, and algal growing conditions ideal.

The maximum waste loadings and treatment costs presented in Chapters X and XI will not be greatly affected by flow regulation considerations, even with construction of either 15 or 16 reservoirs. It appears that the major advantage of flow regulation is for water supply purposes and not for water quality management.

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